Mr. Chase Says—

Bodies are so low as to be both uncomfortable and unsafe. "Body engineers created this style. It's up to them to get us out of this ill-conceived phase of 'low-down' engineering and to show us something rightly proportioned and even better looking."

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Too low a center of gravity tends to increase skidding.

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Three-point chassis suspension, if used, would make possible a more comfortable ride and eliminate many steering difficulties. Chassis and body would also be relieved of twisting strains.

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If we come to a three-point chassis suspension, much of the stiff and heavy bracing now required can be eliminated from bodies.

* * * *

Large size in a car is not essential to good riding.

Compromised Cars

Cars that are needlessly low involve too many compromises. Frames become more expensive to build and have to be made heavier. Ground clearance is barely sufficient on rutted roads or in deep snow. Adequate clearance over rear axles is hard to secure. It is almost impossible for anyone to work under a car unless it is jacked up over a pit. Back axle design becomes difficult and is likely to require weight increases not needed otherwise, because the metal is not disposed to best advantage. Efforts to minimize the size of ring gears and differential housings, in combination with torque and power increases tend to involve rapid gear wear. Now the automobile industry is asking the lubricant manufacturers to produce special extreme pressure lubricants so that gear sizes can be decreased and tooth pressures increased. To what length, indeed, will the automobile engineer not go to save an inch or two in chassis and overall body height? If half as much effort were spent in making the car more comfortable, the public and the manufacturer would profit immeasurably.

Rough Riding?—Rather!

Even yet we have not touched upon the major cause of discomfort, namely poor riding qualities. The latter arise through the use of an antiquated system of suspension, which is far inferior to other components of the car, especially when Hotchkiss drive is employed. Almost the only improvements in a decade in suspension systems is the use of longer springs and a few minor improvements in shock absorbers. It is high time that suspension received more attention.

Most cars ride hard on any but the smoothest roads and wretchedly on rough roads at any but very slow speeds. I doubt whether this condition will be improved materially as long as a four-point chassis suspension continues. Many engineers apparently have jumped to the conclusion that a three-point mounting is all right for everything but the chassis, yet is unstable there!

How many have ever made a real analysis of a three point chassis suspension or attempted to see whether its supposed faults could be overcome? I know one engineer who has done so and he has at the same time produced not alone a stable car but the finest riding one I ever drove. In addition, many steering difficulties are overcome. There is no shimmy; and tramp, if it occurs, has no perceptible effect upon the chassis. Moreover, chassis and body are relieved of twisting strains and the whole car can be made considerably lighter.

Springing Spanked

Again, there is the question of spring types. Why adhere to the practically constant-length spring now universal, especially as such a spring results in hard riding under light load or is too weak for heavier loads? Some thoroughgoing research in the matter of unconventional springs should pay handsomely, especially as I hear that experiments with individual wheel springing have proved rather disappointing.

I am confident, in any case, that highly unstable doughnut tires, as they exist today, and 12-inch upholstery will prove quite unnecessary to give a superlative ride even on rough roads once a really good suspension for the chassis is developed. It is unfair as well as unwise to expect the tire designer and the shock absorber designer to make an inherently poor riding car into an easy riding one. Neither can accomplish the result desired.

There are many small refinements also that would tend to make cars more comfortable. Adjustable driver's seats should be placed on an incline so that they rise when moved forward. There is much to be said, also, in favor of seat backs that move up and down with the passenger instead of polishing his back. If really good chasis suspension is secured, however, there will be no need for deep upholstery. If springs are properly designed, the vertical acceleration will never exceed the gravitational rate—and passengers will never be jounced off the seat or be subjected to the discomfort now resulting from poor springing. In that event, comparatively thin upholstery will be adequate.

Top bows at points over passengers' heads should be eliminated if possible. If not, they should be well padded.

Bemoans Bulk

As to excessive bulk in the present car, much ought to be said. What has been done, in effect, is to design the chassis according to accepted standards, devoting almost half its length to an excessively long engine and cowl, and then to stow what one might suppose is the comparatively unimportant load (the passengers) in the cramped remaining space termed the body!

Isn't it time to consider the motorcar as primarily as a means for conveying passengers in as much comfort as possible? Would it not be logical to dispose of the passenger properly, first, and then treat the means for propulsion as something to be placed in remaining space? If this were

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done, we certainly would have a very different vehicle from the present one! Bus designers are beginning to do exactly this. It is time that passenger-car designers did likewise.

Scarcely 40 per cent of the area a car occupies is devoted to useful load-carrying space. The remainder, including bonnet, cowl, fenders and running boards, a useless space between the spring horns and often as much or more space back of the rear seat, is a total loss so far as carrying useful load is concerned. This arrangement is not logical and not good economy. I do not contend that all the waste space can be converted into useful load carrying purposes, but I am sure that a much larger proportion of it can be and ought to be so converted, and the total size of the vehicle materially decreased.

It is easier to add to the wheelbase if we want more room, and "let well enough alone", so far as general layout is concerned, than to start with a new and sound conception and try to put it into practical form. I suppose we shall continue to follow the former course, until somebody develops a really advanced type of car. Then it will be easy to copy!

Space Makers

Aside from the engine, we get along pretty well with most of the mechanism of the car below the body platform. Modern engines also require very little attention. Why couldn't they be put "below decks" too? They could be, of course, and perhaps be made no less accessible than at present. I think they should be. Flat opposed engines have some important advantages that might be realized. White has pointed the way in a bus engine. For reasons which I have explained at length already in a paper before the Society, I think the engine belongs in the rear of the car, but a flat engine would not necessarily have to be placed there if a forward mounting were preferred. Such an engine might be made to yield much more space for passenger-carrying.

With proper frame design, much more space could be gained by including the area now devoted to running boards within the body.

Fenders, as we know them today, can and should be eliminated, but wheel houses, so far as I can see, must remain. Some space above the wheel houses might well find utility for package or other compartments, however.

With recessed wheels, fenders eliminated, body sides made almost flush with the wheel hubs and the engine stowed away below decks or in the rear of the chassis, a much cleaner exterior would be presented. "True" streamlining would then be much more readily applied than at present. It is a highly desirable step even without the body changes suggested above, although it means rather radical changes in appearance. But whether streamlining is wanted or not, headlamps and other protuberances should be faired into the structure so that the completed car presents a much cleaner (and a much more easily cleaned) exterior than at present.

Irritating Ifs

If, as I anticipate, we come to a three-point chassis suspension, body structures are likely to change materially. Much of the stiff and heavy bracing now required can be eliminated if the body is thus relieved of the severe twisting strains now imposed at present.

The lighter weight and the space economies pointed to as possibilities should go far toward making cars that are less cumbersome and easier to handle. Weight saving, besides reducing power requirements and making a lighter and more economical engine feasible, reduce the size of tire required and make steering easier, a thing much to be desired. If the car is less bulky and lighter it will be easier to park and to handle in other ways.

Small cars with short wheelbase are often associated with hard riding qualities but I greatly doubt whether this follows of necessity. One of the best authorities I know on the subject is certain that large size is not essential to good riding.

Wallops on Weight

I am inclined to take issue with the "cast-iron" school of engineering, the school that is always adding weight to overcome structural weaknesses. This school contends that metal is cheap, and that, at a few cents a pound it is a good investment.

Really efficient weight saving is costly only when it requires more machine work, more expensive or more wasted material. Weight increase runs in a vicious circle. A heavier car requires a more powerful engine; a larger and heavier engine requires other parts of greater weight, and again more power is needed to care for extra weight, etc. Weight saving reverses the process.

Although car designers are to be complimented upon engine developments which have enabled marked power increase within the past decade, they still have a long way to go in achieving compactness, light weight, and higher economy.

More Pokes

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Departures from the conventional four-stroke cycle deserve further investigation.

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The idea that a well streamlined vehicle must have greater over-all length is a mistaken one.

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Elimination or simplification of controls that tend to promote maximum concentration on driving would add to safety and should be encouraged.

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It is unfortunate that more engineers aren't required to clean, lubricate and otherwise care for their own cars. Certainly, their knowledge of accessibility would be increased.

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Excessively low cars have made the service man's job harder.

Much might be gained by studying aircraft engines and adaptation of certain of their features. Certainly some different cylinder arrangement than a simple in-line one might help both in weight saving and compactness. The possibilities in this direction will be still greater if the engine is not confined in a narrow hood.

Departures from the conventional four-stroke cycle deserve further investigation, especially as a throttling four-stroke engine is inherently inefficient under the light loads of average use. The two-stroke cycle, though often condemned because of past crudities, has some remarkable possibilities in respect to compactness, high power for a given size and weight, and high economy at light loads. It deserves more study than it is receiving.

Streamline Sallies

The demand for higher speed has been the occasion for much added weight. Increased speed without basic change in the type of design has necessitated more power, larger and heavier engines and other parts in proportion. One essential factor, however, has been largely overlooked, although it is now beginning to receive some attention. I refer to streamlining. Not the kind so generally referred to in advertising, but a type of streamlining that really effects substantial decrease in power consumption. It demands a complete reshaping of bodies but not, I believe, body lines to which the public will object.

One of the great advantages of streamlining, of course, lies in the marked decrease in power required; a smaller and lighter engine will still propel the car at required speeds. Much weight can be saved on this score and a more efficient vehicle provided. If weight is kept within reasonable limits, there will still be adequate power for rapid acceleration. Thus streamlining will help to reverse the cycle of weight increase and inefficient performance now with us.

There is current a mistaken idea that a well-streamlined vehicle means one of greater over-all length, perhaps because Sir Dennistoun Burney's car was longer than most cars. Jaray has shown, however, that a short car can be effectively streamlined with great saving in power and increased economy and still give ample passenger space.

Socks About Safety

Next in my list of criticsms is that present cars are not sufficiently safe in operation. I concede, however, that great improvements in this respect have been made in recent years and compliments those responsible therefor.

Better vision in all directions, nevertheless, should be provided. Rear windows should be large and all pillars narrower. I shall not be surprised if a way is found to eliminate windshield pillars, especially in cars with rear engine mounting. If body racking is virtually eliminated, as it can be with a three-point chassis mounting, pillar stresses can be greatly reduced and pillar size decreased accordingly.

The same type of mounting with the front axle positioned by radius rods can be made to improve steering layout and to avoid wheel "fight" and most other steering difficulties. It will also make steering easier. All three items will add materially to safety.

Although much has been done to improve lighting and to reduce the glare produced by headlamps, there is still much room for improvement on both scores.

Why not have headlamps that cannot get or be put out of adjustment by any ordinary means? Perhaps this is too much to expect, but I recommend that it be put down as one of those things to be aimed at.

Reflecting surfaces are often a source of danger. I question the use of polished plate on spare tire covers mounted at the rear of cars. Windshield reflections have been made less annoying by sloping the glass. If front window glasses could be sloped also, other annoying reflections might be avoided.

Better braking, perhaps with power application, can also add to safety, although there is far less room for improvement in this respect than there was a few years ago. Construction that keeps water and oil away from braking surfaces and always maintains the latter in optimum condition has advantages which are so obvious that they are often overlooked.

The elimination or simplification of controls that tend to prevent maximum concentration on driving would add to safety and should be encouraged. Automatic choke and heat controls are a step in this direction.

If, as seems likely, the gear shift can be eliminated, there would be further gains in safety and in convenience of driving and perhaps also in mechanical simplification. European developments in which hydraulic turbo-torque-multiplying devices are employed merit study on this score, especially as the amount of driving done today in any but top speed is very small.

Safety Factors

I have no quarrel with radios in general at the proper time and place but I question their use in an automobile, at least when it is in motion and the driver diverts his attention to tune it or to listen to it. Its use under this condition is not in the interest of safety. The driver has quite enough to do to concentrate on driving under modern traffic conditions without such distractions. If he must have a radio and use it while driving the controls for it should be as simple and easy to read as a hand throttle, and should not involve a figured dial. Otherwise the car may climb a pole while attention is diverted to tuning.

Hand brakes are no longer called emergency brakes, I suppose, because they are seldom of much use in an emergency, and often leave much to be desired even for parking purposes. This certainly does not make for safety. Some hand brakes are so badly placed that short-armed drivers cannot reach them at all!

Few designers are required to clean, lubricate or otherwise care for cars of their own design. I am serious when I say that this is unfortunate! There is, of course, a large group of other owners who never perform such operations, but I am sure they are in a minority, especially since 1929. The owner who cares for his own car doesn't enjoy standing on his head or wallowing on his back or his belly to get at inaccessible points that need lubrication or bolts that need tightening. Perhaps if more car designers tried it they would see that fewer points require lubricant and that the number of inaccessible items needing occasional attention are minimized. May I suggest also that there is at least one type of spring, and a mighty good one too, that requires no shackles or other substitute fastening to the chassis? Its use would eliminate the need for about a dozen points that require lubrication on most cars as well as of as many parts that are a constant source of squeaks or rattles in the average car.

I also recommend that the porous bronze bushing be considered for numerous applications.

Water pump glands and bushings give frequent trouble for lack of careful design and lubrication. Grease cups on pump bearings are uncertain and in some designs where pressure gun fittings are used in their place a service station attendant with a gun operating under several hundred pounds pressure may shoot several pounds of grease into the cooling system without knowing it! Porous bronze bushings work well in such applications. They require no oil holes, yet oil or grease can be fed through their pores from a surrounding chamber with the greatest ease. There is nothing very new about these facts, yet an examination of almost any modern chassis will show that they are almost totally disregarded in a great many instances.

Complication Complexes

My indictment declares that present cars are too complex. This is an easy charge to substantiate. It is not so easy to avoid. Unfortunately the elimination of manual controls in favor of the automatic type almost invariably leads to complication, but may be well worth it. It has had this effect in recent developments but the added complexity must make the service managers gasp—if that's the right word. Whenever new construction is contemplated a competent engineer and experienced production and service men should be delegated to study the proposed design with the sole purpose of simplification in mind. I believe that their combined efforts would invariably save far more than their time costs, for I am convinced that hurried designs result in much unnecessary complication.

Much the same might be said about cars being hard to service, and about the possibilities of a similar remedy. A great deal has been done and is still being done to minimize the need for service, and the modern car is remarkably trouble-free. Nevertheless, some of them still require that the rear axle be moved back and the gearset be taken off to permit replacement of clutch facings. This is not my idea of maximum accessibility! Excessively low cars have made the service man's job harder also, and so has the modern vogue for hiding everything mechanical behind skirts or aprons of sheet metal. The end may justify the means but it may also ruin the disposition of service men! In any case, a little more forethought certainly would eliminate countless service troubles. The passenger-car designer could learn a lot about accessibility if he could find more time to spend in the service station. Studies of modern bus design might also prove profitable even though the service problems to be met are far from being identical and buses are not yet perfect by any means with respect to accessibility.

Recent developments have resulted in easier starting and smoother running during warming-up periods, but there is room for further improvement in both respects especially in cold weather. Better ventilating means might be provided to advantage on most cars and better heating facilities for cold weather would also be appreciated where much cold-weather driving is done. There are some advantages in steam cooling and steam heating systems still to be realized in practice.

These are only a few of the possible refinements that might be effected. I shall rest my case, however, and leave those who have followed this "brief for the prosecution" to judge which counts in this indictment shall stand and which shall be quashed.

What Executives Think of College Men

SUCCESSFUL executives can be divided into three schools of thought with respect to their attitude toward college graduates. Those of one school, and I am glad to say that it has a declining membership, shrink from the thought of a graduate in the shop. This school includes executives who usually have come up from the bottom and value the details and the experience of their progress more than they do the fundamentals or theory. They believe in making the details right and the fundamentals will take care of themselves. The most capable can supervise the design of an engine without a single calculation and, in a number of cases, have produced the mechanical designs that have had the greatest commercial success. They are, with a few notable exceptions, the heads of our most successful plants.

The next class usually consists of executives whose fathers, grandfathers and uncles, back to the Mayflower, have all been graduated from the same school, belonged to the same fraternity and made the football team, the crew or the track team. To these men, no brains or progress can be called such if it has not been branded with a diploma, and few men really arrest their attention who have come up from the bottom with only a meager education. Of course, this is the extreme of that type. Executives of this class, as well as the first, are likely to hold onto old products too long or let competition beat them out by being too cock-sure of their market. In the first class, this comes from too much self-confidence and too narrow a viewpoint; and in the second class it comes from vanity and arrogance. This second class usually fails from overhead and succumbs to the illusion that a real executive never works but sees that others do. They are like many unfortunates in the world who are incapacitated in some way and, therefore, are perfectly satisfied to tell you what to do in any circumstances but cannot do it themselves or tell you how. This class has a hard time adjusting to depression and, when cutting wages, lay off $75 stenographers and, when they are through, fail with a staff of fraternity dependents.

The third class of executives is comprised of a balanced, sound type of executive who knows that he has to have both classes to win: the thinkers and the doers, the college men and the shop men, the research men and the practical men, the men with foresight and a few with good hindsight who can tell when a great mistake has been made and have the ability not to do it again. The man of this type may be a college man or one who has come up. No matter where he has come from, he recognizes that, in this age, the man is likely to be great who can first see what direction progress is to take and then follows through.—From an Annual Meeting paper by H. L. Horning, S.A.E. Past President, president, Waukesha Motor Co., Waukesha, Wis.

Airplane Flight Testing for Maximum Speed

By F. M. Thomas

and

H. W. Fairchild

THIS paper tells how to obtain and evaluate maximum speed of airplanes in level flight.

Relationship between available thrust horsepower and powers required to overcome both induced and non-induced resistances is given, in order to provide a clearer understanding of the items affecting maximum speed and the various ways of evaluating changes in that speed.

Maintenance of a constant density altitude in combination with a constant engine power or airplane speed is most satisfactory, the authors show.

Charts enabling a pilot to attain these conditions in flight are given, together with a method of manifold-pressure calibration of the engine and the use of such calibration in determining the engine power in flight.

MOST of the previous publications on airplane flight-testing for maximum speed have dealt with the problem as a subordinate topic under routine performance-testing. Numerous articles have covered thoroughly the methods and technique of maximum-speed measurement, but the problem has then been dismissed without any comprehensive discussion of the items affecting maximum speed and of methods of evaluating changes in these items. This paper deals primarily with these last two phases of the question and describes certain methods and technique which in actual practice have given satisfactory results.

A value for the maximum speed of an airplane is important, not only as a desirable performance characteristic for that particular plane, but also as a basis for the comparison of the effects of changes that may later be made. These changes may be grouped into three broad categories. Foremost is the group embracing changes in the drag condition of the airplane; notably, modifications of cowls and fairing of all kinds. Changes in gross weight, with their effect on induced drag, should also be included here. The second group includes changes in horsepower, the qualitative-test effects and calculated quantitative effects of which are well understood, but whose quantitative-test effects have been obscured by conventional flight-test technique. In the third group are changes in propeller conditions involving diameter, speed of rotation, number of blades and blade form. For all of these groups maximum speed is one of the most important criteria, yet, without satisfactory regulation of the variables not being tested, any results obtained are likely to be deceptive.

It is necessary to consider first those items affecting the measurement of the speeds and then those items affecting the speeds themselves. In the first classification are methods, instruments, atmospheric conditions and technique. We have confined ourselves to a very brief survey of the measurement of speed and a few pertinent suggestions which, during the past two years, have been found useful. It is with the second group, things affecting the actual speed of the airplane, and with methods of appraising changes in those things, that this paper is chiefly concerned.

Measurement of Speed

Time Speeds and the Air-Speed Indicator Calibration. Many methods have been used to measure maximum speed, but perhaps the most practical is the timing of the airplane over a measured speed-course. The speed-course provides a means not only of determining the top speed but also of making a calibration of the air-speed indicator for use later in obtaining speeds at altitudes. Accuracy in calibration is dependent largely upon suitable atmospheric conditions and correct technique. An excellent general survey of the situation was given by Lieut.-Com. E. W. Rounds in a recent

[Mr. Thomas is aeronautical engineer and Mr. Fairchild engineering test pilot of the United Aircraft & Transport Corp., Hartford, Conn. This paper was read at the 1933 Annual Meeting of the Society.]

paper[1]. Our work has brought to light the following additional suggestions:

(1) Regardless of the altitude at which the maximum speed is being tested, the mixture control should always be adjusted for a best-power condition. The power is nearly constant over a considerable range of mixture settings. In flight, the mixture control is set for the lean end of this range. This usually is done by leaning out until the engine speed has reached its maximum and begun to decrease. The peak is regained by enrichening a little too much and then leaning out slightly.

(2) While flying the speed course, the whole attention of the pilot should be devoted to maintaining constant indicated air-speed, constant altitude and to reading the instruments. The readings can be recorded while circling for the next approach. An observer is desirable because of the large number of readings that must be taken in a short time, but, when there is no observer, the pilot can simplify matters by noting, in addition to those items which must be read on each trip over the course, one, such as altitude, which remains essentially constant. The number of readings required on each trip may thus be reduced.

(3) Eight readings are desirable: time for the course, average indicated air-speed, average engine speed, pressure altitude, both dry-bulb and wet-bulb, strut air-temperature, absolute intake-manifold pressure and carbureter-intake air-temperature. While only time, air speed, altitude and dry strut air-temperature are necessary for the calibration of the air-speed indicator, the other readings enable the determination of the engine horsepower, as will be described later. Except for indicated air-speed and engine speed, which should be observed continually and averaged for the course, the final readings should be taken while flying the last half of the course so as to assure the attainment of constant conditions.

(4) At points below full throttle on the air-speed-indicator calibration, the duplication on the return trip over the course of the air speed obtained while flying in the other direction can be made most easily by setting the throttle for the same intake-manifold pressure.

The average of the full-throttle timed speeds is the maximum true speed at the density altitude of the test, provided the other test conditions, such as wind, are satisfactory. The air-speed-indicator calibration is obtained by averaging the timed speeds at any given throttle setting and multiplying these by $\sqrt{\rho/\rho_o}$, the square root of the air density existing at the time of calibration to the standard sea-level density and plotting these values against the corresponding average indicated air-speeds. In general, the calibration curve is drawn from point to point, but, if a large number of points are available, or if some of them are of questionable accuracy, a faired mean curve is better. With a considerable number of points obtained under suitable test conditions, the accuracy of such a calibration should be within ½ per cent. One such calibration recently obtained consisted of 20 points run on four different days over a period of six months, two different speed courses being used. The airplane was powered with three different engines and flown at indicated speeds from 60 to 207 m.p.h. The maximum deviation of points from the mean curve was less than 1 per cent. No change in the pitot-static head, connecting pipes or air-speed indicator was made. It is evident that the calibration was affected very slightly, if at all, by the changes of powerplant.

Instruments. The instruments necessary for obtaining the readings mentioned have been covered in detail in another paper[2] presented at this meeting. However, it is worth while noting at this time a few pertinent facts about them. For speed-course measurements, a good, calibrated tenth-second stop-watch is desirable. Personal errors involved do not justify any greater accuracy. The dry-bulb strut thermometer should have its bulb protected from the direct rays of the sun, yet have sufficient ventilation so that little lag occurs in its operation. A sensitive altimeter with divisions readable to 20 ft. is recommended because of its double usefulness in giving the pressure altitude accurately and in providing a means for flying level at altitude. Altimeters in open cockpits are subject to an error because of the reduced pressure due to the combination of cockpit shape and air-stream. For high-speed airplanes this error may amount to as much as 400 ft. on the high side. The altimeter can be calibrated for this error by flying at various speeds past some vantage point where the existing pressure altitude can be measured. A better method, however, is the preclusion of the error by the connection of the altimeter to the static line of the air-speed indicator.

In the United States at the present time the pitot-static type of air-speed indicator[3] has reached almost universal acceptance because of its ruggedness, satisfactory differential pressure and ease of reproduction without variation in calibration characteristics. However, this type is not free from

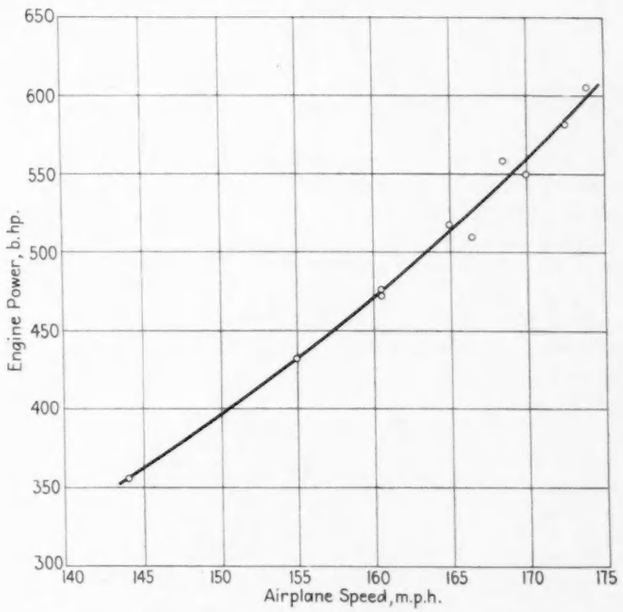


Fig. 1—Flight-Test Variation of Airplane Speed with Engine Power

These data were obtained by flying at a constant density-altitude of 2000 ft. and a constant engine speed of 2000 R.P.M. Each point is for a separate propeller-pitch setting.

Similar curves for the airplane in other drag conditions would give a direct comparison of either the airplane speeds at a given engine power or the power required to maintain a certain airplane speed.

Sometimes a peculiarity in the shape of such a curve discloses an irregularity which would otherwise have been overlooked but which warrants special consideration.

[1] See S.A.E. Journal, May 1931, p. 511.

[2] See Commercial Flight-Test Equipment and Methods, by A. L. MacClain and D. S. Hersey.

[3] See N.A.C.A. Report No. 420, Aircraft Speed Instruments, by K. H. Beij, 1932.

errors. Location of most pitot-static heads a relatively short distance ahead of the wing results in an appreciable position error. This error has been measured on some high-speed airplanes and at times was found to be so much as to give a reading 19 m.p.h. below the correct one[4]. Gusts cause some unsteadiness in the readings of air-speed indicators, more because of too lightly dampened pointers than because of errors in the mean speed. The variation from the correct reading caused by the inclination of the pitot-static head may be overcome by utilizing a swivel head or a suspended head. When an indicator is calibrated over a speed course, the inclination and position errors are combined with the scale error. The calibration is not vitiated by any density effect at altitude; each indicated air-speed is associated with only one angle of attack and the inclination error at any particular indicated air-speed thus does not change. It should be particularly noted in this connection that devices such as slots and flaps, which change the attitude of the airplane for a given air-speed, render invalid any calibration of a fixed pitot-static head made without them. Large changes in gross weight and markedly different stabilizer settings have the same result, but to a lesser extent.

The readings of most of the pressure instruments now in use are substantially independent of temperature over the range encountered in flight testing.

Indicated Air-Speeds. Little difficulty is experienced in maintaining level flight over the speed course because of the proximity of the ground. At altitudes a statoscope, sensitive altimeter, or barograph is used to maintain a constant-pressure level. The location of the barograph in the airplane usually is such that it is not easily readable by the pilot. A statoscope is satisfactory, but a special altimeter may be equally sensitive and give the actual pressure altitude as well.

In running maximum speeds at altitudes the pilot should first set the horizontal stabilizer so that no stick force is required with both the mixture and heat controls set to obtain approximately maximum engine speed. Final adjustment of the mixture control, which should be made with the greatest care, can then be effected, with a minimum of the pilot's attention required to maintain level flight. Both the air-speed indicator and the altimeter should be observed closely during and after these preliminary adjustments. If both remain constant for a period of at least 2 min. and the engine speed remains at its maximum value, the readings can be recorded. The strut air-temperature and such other readings as may be necessary for the subsequent determination of engine power should be recorded last.

No amount of piloting technique, of course, can overcome unsuitable atmospheric conditions. Rising or descending currents of air in the vicinity of clouds and cities will cause grave errors in the speed obtained, as will also rough air. Although the latter may materially affect the actual speed of the airplane, bumpy air is of prime importance in test flying because it aggravates the already sufficiently difficult problem of reading the instruments. It is interesting to speculate on the effect upon actual airplane speed of vertically moving air currents when an indicated speed run is made at a constant-pressure altitude. Their presence usually cannot be detected by the pilot, and so his hope of obtaining accurate results is a fore-knowledge of conditions under which they are likely to occur and the avoidance of such conditions.

[4] See Reports and Memoranda No. 1472, Measurement of Position Error on High-Speed Aircraft, by R. K. Cushing, April, 1932.

In the calculation of the true speed from the observed data, the indicated air-speed reading is first corrected for errors derived from the installation and for instrument errors by using the calibration obtained over the speed course. The true speed is assumed to be equal to the product of this correct indicated speed and the square root of the ratio of the density at sea level to the density at the altitude in question ($\sqrt{\frac{\rho_o}{\rho}}$) as determined by the readings of pressure altitude and dry strut-temperature.

Factors Affecting Speed

Up to this point, the problems of flying level and at the highest speed possible, of measuring this speed and reducing it to its true value, have been considered, and no attempt has been made to interpret it. The correct evaluation of maximum speeds is involved and difficult. Frequently we find airplane speeds being compared and incorrect conclusions being drawn because the test values were not truly comparable. The meaning of an airplane maximum speed, that is, its relation to other measured speeds, can be understood only through full knowledge of its variation with airplane, propeller and engine characteristics.

The factors affecting the maximum speed of an airplane and the character of their influence upon it are shown in the equation:

$$\eta \text{ b.hp.} = \frac{A_e V^3}{114300}\left(\frac{\rho}{\rho_o}\right) + \frac{1}{3.01V}\left(\frac{W}{b}\right)^2\left(\frac{\rho_o}{\rho}\right) \quad (1)$$

Where

η = propulsive efficiency of the propeller
b.hp. = brake horsepower of the engine
A_e = equivalent flat-plate area of the whole airplane, in square feet
V = true speed, in miles per hour
W = gross weight, in pounds
b = equivalent monoplane span, in feet
ρ = air density at altitude in question
ρ_o = air density at standard sea level

In other words, the total thrust horsepower available is equal to the sum of the thrust horsepowers required to overcome both the non-induced and the induced drags respectively.

Power Required. Of the two terms in the right member of the equation, the thrust horsepower required to overcome the induced drag is much the smaller. The effect of a change in gross weight, W, on the induced drag is relatively unimportant except in the case of slow-speed or high-altitude airplanes. These two characteristics do not often occur in combination. On a moderately high-speed airplane of the observation type recently tested, a change in gross weight of about 5 per cent was found to cause a change in top speed of less than the experimental error involved, and Equation (1) shows that this should be a general conclusion. For all comparative tests the gross weight should be kept as nearly constant as convenient, although small changes will cause negligible errors in speed. For fast airplanes flown near sea level, even relatively large changes in gross weight are of little importance for maximum speed.

Factors affecting the equivalent monoplane span, b, such as the ratio of gap to span, the ratio of spans and the proportional area in the two wings are not often altered and then usually involve changes in non-induced drag.

Most comparisons of maximum speed will involve changes in items affecting the non-induced drag. The number of items included in this category is very large and of infinite variety. Ring cowls, wrapper and nose cowls, wheel pants, wing-root fairings, strut cuffs and windshields—changes in

these and similar items are normal steps in the progress toward aerodynamically cleaner airplanes. Certain of these things, lying in the slipstream, notably ring cowls, affect to some extent the propulsive efficiency as well as the drag.

Power Available. If an airplane has certain power-required characteristics, its maximum speed will be determined by the thrust horsepower available from the powerplant, the product of engine power and propulsive efficiency. The importance of the latter factor should always be considered in running comparative speed tests. The extent to which it can be controlled is included later in a discussion of the ways of running such tests.

Engine power, b.hp., must be known if an accurate evaluation of maximum speeds is to be made.

For any given engine, the brake horsepower is a function of the engine speed, the exhaust back-pressure, and the temperature, pressure and humidity of the charge. All of these quantities can readily be measured in flight. If a suitable dynamometer calibration of the engine is available, the actual brake horsepower delivered in flight then can be determined. Of these constituents of brake horsepower, the most important are engine speed and intake-manifold pressure. Engine speed has almost always been measured as a check on engine operation, but only with the advent of supercharged engines has the value of the intake pressure been realized.

Very often the propeller pitch is not reset to maintain the same full-throttle engine speed in a comparison of maximum speeds involving changes in the drag condition, and a serious error is thereby introduced. For example, removal of the cockpit ventilators on a certain airplane caused an increase of 30 r.p.m. in engine speed. Neglect of the effect which this had on the brake horsepower would cause an error of more than 20 per cent in the change in speed attributable to the ventilators.

Many airplane designers take advantage of the possibility of obtaining increased power from the engine by constructing the carbureter air-intake scoop so that it utilizes the dynamic pressure of the air-stream. High-speed airplanes in particular can make use of this effect to a great extent. The ramming head of the free air-stream is augmented by the propeller slipstream. Changes in engine cowls are very likely to affect this ramming head as well as the drag condition of the airplane; hence any resulting change in speed probably is a composite effect of the changes in both the drag and the engine power. In one test we made recently, the shift from a small projecting air-scoop on the side of the wrapper cowl to an intake flush with the wrapper cowl caused a loss of 0.9 in. of mercury in intake-manifold pressure and 30 r.p.m. Of the 36 b.hp. thus lost, 25 were due to the drop in manifold pressure and 11 to the drop in engine speed. The loss in air speed due to decreased power more than offset the gain from reduced parasite drag. This dynamic-pressure effect obtained in flight makes the usual full-throttle power calibration supplied by the engine manufacturer unsuitable for the measurement of power in flight unless elaborate corrections are applied.

Brake horsepower is normally considered as being inversely proportional to the square root of the absolute temperature of the charge. In flight it is not sufficient to measure the strut air-temperature because the actual temperature of the air taken into the engine is nearly always higher than this, due to the proximity of the powerplant and sometimes to leakage through the valve of a hot-air stove when it is supposed that cold air is being used. The air temperature in the intake system is taken just below the carbureter, the same place that it is measured on the dynamometer. The rise in temperature here may vary from 5 to 65 deg. fahr. This would amount to a maximum-horsepower loss of about 6 per cent, or 2 per cent in speed, an amount that is by no means inappreciable. Here, again, changes in engine cowl may affect power as well as drag by creating different temperature conditions in the intake system.

Humidity is a minor factor that can be neglected without any great error in power. Maximum speed ordinarily will not be run when the relative humidity is greater than 75 per cent. The correction for humidity is applied as a reduction of the absolute intake-manifold pressure. It has been found that the correction for humidity effect on engine power should be applied in the same manner at altitudes up to 25,000 ft. as at sea level[5]. At 60 deg. fahr. air temperature and 75 per cent relative humidity, this correction amounts to 0.4 in. of mercury, or approximately 8 b.hp. on a 600-b.hp. engine. Since the humidity correction is normally much less than this, its effect on airplane speed is practically negligible.

As the pressure of the atmosphere into which an engine is exhausting is decreased, an accompanying increase in power occurs. Comparative speed runs usually will be made at approximately the same altitude. In these cases the back-pressure corrections will be substantially the same.

A suitable dynamometer calibration of the engine is indispensable for the utilization of the flight data mentioned. This calibration consists of curves, at various constant engine speeds, of brake horsepower plotted against absolute intake-manifold pressure. The observed dynamometer brake-horsepower has been corrected for carbureter air-temperature and the manifold pressure for humidity.

The actual brake horsepower in flight is obtained from the data by first finding the true absolute manifold pressure; that is, the difference between the gage reading corrected for instrument error and the vapor pressure in inches of mercury as determined by the wet and dry-bulb thermometer readings. Using the true absolute manifold pressure and the engine speed, the brake horsepower is read from the engine calibration and then corrected for back pressure and carbureter-intake air-temperature to obtain the true value.

Measurement of all of these items in flight is a straightforward procedure. Any reliable tachometer will suffice for the engine speed. The absolute intake-manifold pressure is measured in an intake pipe near the cylinder port with a gage which is nothing more than a sealed altimeter graduated preferably in inches of mercury. Any temperature gage of suitable range is satisfactory for measuring the intake air-temperature just below the carbureter, but a thermocouple used in conjunction with a potentiometer or pyromillivoltmeter is often more convenient because such equipment may also be used to measure cylinder temperatures. For vapor pressure, the dry-bulb temperature is given by an ordinary mercury or distant-reading strut thermometer located outside of the effect of the powerplant. A special thermocouple psychrometer gives the difference between wet and dry-bulb temperatures. The back-pressure correction is, of course, a function of the pressure altitude, so that any altimeter which gives the pressure at the point where the exhaust leaves the engine is suitable for its determination.

Care should be taken always to measure these quantities in flight at the same places that they were measured for the

[5] See N.A.C.A. Report No. 426, The Effect of Humidity on Engine Power at Altitude, by D. B. Brooks and E. A. Garlock, 1932.

dynamometer calibration. Otherwise the readings obtained cannot be legitimately used with the power-calibration curves. The importance of good calibrations of all instruments should also be borne in mind.

It is thus possible with suitable ground and flight facilities to measure quite accurately the power of the engine in the air. Actual conditions existing during the flight tests are measured by direct methods, and a reduction to the desired quantity, b-hp., is made by using these data and the dynamometer calibration of the engine. It may be advisable in doubtful cases to verify the engine power-characteristics by a check calibration after the flight tests. With a knowledge of this previously uncertain variable, maximum-speed testing is put on a new and sounder basis, for not only can the actual speed be found, but one of the major factors affecting the speed can be segregated and measured.

Reduction to Standard

The expression "reduction of maximum speed to standard altitude" is perhaps confusing. Suppose that an airplane has been flight-tested at altitude and that the true speed in level flight and the pressure and temperature of the air during the test were measured. Since maximum speed varies with altitude, that speed cannot be compared with the speeds of other airplanes until some figure is assigned to the altitude at which the test was made. The assignment is made by relating the test conditions to those of a standard atmosphere having a definite relation between barometric pressures and temperatures at each tape-line altitude above sea-level. It is improbable that on any particular day these conditions will be "standard"; that is, that the observed temperatures and pressures at the altitude where the maximum speed was measured will coincide with any particular altitude in the standard atmosphere. This presents the problem of finding out at what altitude the observed airplane speed would have been obtained if the test had been made on a standard day; this process is called "the reduction of the speed to standard conditions".

Let us now consider the statement of the factors affecting the speed, Equation (1). It is evident that the power-required characteristics of the airplane are influenced by altitude only to the extent that the air pressures and temperatures determine the air density; in other words, power required is a straight density function. If the engine power is known, the speed at which the propeller will turn for a given pitch setting and air speed is determined by the air density. Although no proof of these propeller variations will be given here, it may be stated that under these conditions propulsive efficiency also is a density function. Thus, where engine power is observed along with the air conditions, the measured maximum speed is that which would have been obtained with that power at the standard altitude having the same density as the air in which the test was made; that is, the reduction to standard should be made upon a density basis.

For the foregoing case it is necessary to state engine power as well as altitude and airplane speed. If any systematic variation of power with altitude occurs, the power may be given for only one altitude and the speeds given for all altitudes. Efforts have been made to write the power of an unsupercharged engine as a function of the air density, and, if this is true, the entire reduction to standard should be made upon a density basis. The change of engine power with altitude may be stated as a function of the air density when a given air pressure is always associated with a certain temperature, as in a standard atmosphere. In flight testing, however, such is not the case and recourse must be made to the various factors herein discussed which determine engine power. The factor which alone has the greatest influence is air pressure. Therefore, since power has such a great effect on speed, it is sometimes considered in this Country to be more accurate to plot true speed against pressure altitude. The empirical foundation of this practice is firmer than the theoretical.

This reason for reducing maximum speeds to the standard-pressure altitude does not exist for all supercharged engines below critical altitude, because for these cases the variation of power with altitude is purely arbitrary. If at sea level the maximum power permitted is determined by a throttle stop and if the throttle is not advanced beyond the stop until critical altitude is reached, the same arguments for reduction on a pressure basis hold as they did for the unsupercharged engine; but, if the throttle is advanced gradually, some other basis may be equally satisfactory. To decide on the best method of reduction, it is necessary to have a general rule of the variation of power with altitude. At present the differences of operation of supercharged engines below critical altitude are so great that no such rule can be laid down. For the time being, it probably is best to use the same basis below critical altitude as above. Whatever may be the shortcomings of this method, it at least avoids a discontinuity at critical altitude. Failure to state specifically how the engine was operated below critical altitude usually is a much more serious detriment to the comparative interpretation of maximum speeds than is the question of the method used in reducing the data.

When curves of maximum speed against standard altitude are available, comparisons among airplanes can be made directly by quoting the speeds at one altitude, such as sea level, for airplanes having unsupercharged engines. Frequently only one speed-course point is available, which is not necessarily at standard sea level. It is evident from the difference in variation with altitude of the two parts of the airplane power required (See Equation (1)) that the slope of the curve of speed against altitude is dependent upon the characteristics of the airplane and that no average slope based only upon temperature and pressure, for instance, which leaves unstated the relative importance of induced and parasite resistance for that particular airplane can be correct. This fact is amply supported by performance calculations and by analysis of flight-test data. Fortunately, for the normally aspirated engine, maximum airplane speed near sea level does not vary greatly with altitude. Strictly, and especially for supercharged engines, the measured engine power and density altitude should be reported with the timed maximum speed, or else the speed should be calculated from Equation (1) for sea level density and the actual power. It will be found for most airplanes near sea level that the increase in maximum speed at constant power is very close to 1 per cent for each 1000 ft. of increase in density altitude.

Bookkeeping and General Considerations. One of the most confusing problems in applied flight-testing is what might be called the bookkeeping of comparative speed trials. When it is desired to find out what can be done to increase the speed of an airplane, the number of changes in fairing which seem to be worth testing grows rapidly, and the number of possible combinations of fairings may easily become impractically large. To test each combination is not necessary unless it is suspected that the whole is not equal

to the sum of its parts, as is sometimes found with peculiar interference effects. But the importance of having some definite, simple and preconceived system of keeping track of and recording the results cannot be over-emphasized.

The problem is triply complicated because it involves balancing against convenience in bookkeeping the more influential factors, convenience in making the mechanical changes on the airplane and in flying the tests. All important in any test is the necessity of making one and only one change at a time. For instance, a lower speed caused by removing the wing-root fairings and the fairings around the strut ends is interesting but is not conclusive evidence of the value of either item. Removal of the strut cuffs may have caused a negligible loss in speed, most of it having been accounted for by the wing-root fairings. If so, the strut cuffs were not worth their added weight, cost and complexity. Only careful separation and control of each test will accurately determine the value of the changes made.

More confusing than the lumping of two or more changes in one test is the unintentional neglect of items that may seem to have little effect but which, in reality, exert considerable influence on the result. As illustrations, consider first the test of a ring cowl which does not take into account the presence or absence of intercylinder baffles. Actually, such baffles in an uncowled radial air-cooled engine may easily change the maximum speed by an appreciable amount. If the cowled engine must be flown with baffles because of engine-cooling considerations, the question whether to use the speed of the uncowled engine with or without baffles as the basis for determining the value of the cowl must be decided. In another case, the two parts of a comparative test were run on a hot and on a cold day. In the first instance, the pilot opened the shutters in the nose cowl, and, in the second, closed them to keep the engine warm. This change alone caused a variation in speed of more than 2 m.p.h., even if the speeds are corrected to equal horsepowers.

The order of running tests involving consecutive changes in fairings will affect to a slight extent the quantitative values of the results. For example, the gain in speed from wheel pants will vary a little, depending on whether the basic speed used for comparison was obtained with or without a ring cowl on the engine. The greater gains from such improvements in fairing will be found on the higher-speed airplanes. It is suggested that the test program provide for the minor changes in fairing to be made upon the fastest airplane-condition. This effect is small, however, except in cases where some of the changes in the airplane cause very large changes in speed.

Purposes of Maximum-Speed Testing. Distinction should be drawn among the various kinds of maximum-speed tests, because it often is possible to eliminate many of the inaccuracies inherent in a comparison of maximum airplane speeds by running the flight tests in a particular manner to emphasize the desired characteristic. The different objectives of maximum-speed tests may be classified as follows:

(1) To obtain the maximum speed of the engine-propeller-airplane combination. This should be done under stated conditions of the whole combination, including atmospheric conditions; the problem of correcting from one atmospheric condition to another then exists
(2) To find the effects of changes in engine power
(3) To find the effects of changes in over-all propulsive efficiency
(4) To find the effects of changes in over-all airplane characteristics, such as (*a*) parasite resistance and (*b*) induced resistance

The problem of determining which set of test conditions will be most satisfactory for a certain test is made extremely difficult by the complex interrelations of the factors affecting the maximum speed.

Ways of Running Comparative Tests. Each of the last three objectives can be more easily attained if at least some of those variables not being tested can be eliminated by holding them constant. For certain types of tests it might be desirable to hold one or more of the following items constant.

(1) Propulsive efficiency
(2) Indicated air-speed ($V\sqrt{\rho/\rho_0}$)
(3) Power required to overcome induced resistance
(4) Power required to overcome non-induced resistance
(5) Air density
(6) Engine power

Let us consider first the possibility of running comparative tests at a constant propulsive efficiency. Large-scale wind-tunnel tests on propellers yield much valuable information about propulsive efficiency but they do not and cannot furnish data for the exact determination of efficiency under all conditions. The essential factors which affect the propulsive efficiency of a propeller of any particular design series are blade angle, V/ND, tip speed, and interference. Let us suppose that the last two of these characteristics—tip speed and interference—are eliminated from the type of comparative speed tests under discussion. If, then, a propeller is tested at the same blade angle and V/ND, for comparative tests we shall assume that its propulsive efficiency is constant. The power absorbed by a propeller may be written

$$P = P_c \rho V^3 D^2 \qquad (2)$$

where

P = power absorbed by propeller
P_c = power coefficient dependent primarily upon blade angle and V/ND
D = propeller diameter

For a constant diameter, blade angle and V/ND, this becomes

$$P = K_1 V^3 \left(\frac{\rho}{\rho_0}\right) \qquad (3)$$

The power absorbed by the propeller must be equal to the power output of the engine and must equal the power required by the airplane in level flight.

$$K_2 V^3 \left(\frac{\rho}{\rho_0}\right) = \text{b.hp.} = \frac{1}{\eta}\left[\frac{A_e V^3}{114300}\left(\frac{\rho}{\rho_0}\right) + \left(\frac{W}{b}\right)^2 \frac{1}{3.01\, V}\left(\frac{\rho_0}{\rho}\right)\right] \qquad (4)$$

We are interested in finding whether it is possible to fly under conditions in which the power absorbed by the propeller at constant pitch and V/ND can be varied in such a way as to equal the power required by the airplane after modifications have been made in its drag characteristics. Equation (4) may be written:

$$K_3 = \frac{A_e}{114300} + \left(\frac{W}{b}\right)^2 \frac{1}{3.01\ (V\sqrt{\rho/\rho_0})^4} \qquad (5)$$

This shows that the total power required by the airplane at a given air-speed and air density must remain constant; in other words, if a change is made in the parasite term of the airplane, there must be an opposite change of equal magnitude in the term representing the induced resistance. For an airplane of constant weight and span, this would mean large changes in the indicated air-speed ($V\sqrt{\rho/\rho_0}$) at which the test is made. This is impractical first, because at sea level the induced factor is ordinarily about 3 to 10 per cent of the non-induced factor; second, because a change in indicated air-speed means a change in angle of attack of the airplane and the consequent introduction of a serious unknown; third,

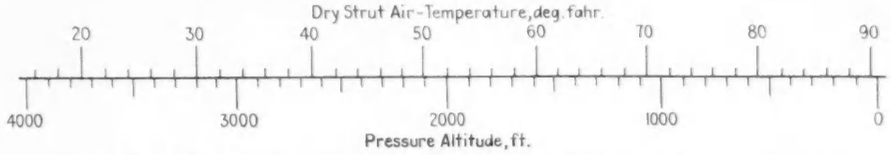


Fig. 2—Pilot's Chart for Flying at Constant Density-Altitude

This chart is for a standard density-altitude of 2000 ft. In flight, the pilot varies the pressure altitude until its relation to the actual strut air-temperature is that shown by this chart.

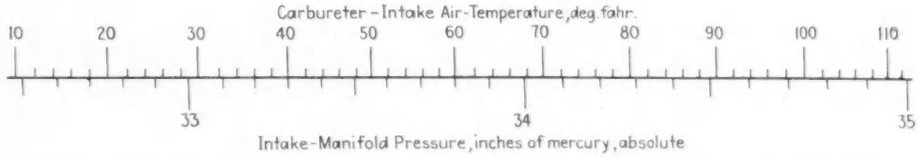


Fig. 3—Pilot's Chart for Flying at Constant Engine Power and Constant Engine Speed

This chart was constructed from the engine dynamometer-calibration and from the assumption that the power varies as the inverse square root of the absolute temperature. It further assumes that between comparative tests the changes in power due to changes in exhaust back-pressure and air humidity are negligible.

When the carbureter-intake air-temperature has reached a maximum in level flight at the proper altitude, the pilot adjusts the throttle to give the relation between temperature and intake-manifold pressure shown by this chart.

The engine speed is held constant by varying the propeller pitch.

because, if large changes in altitude are made, the accuracy of the engine calibration greatly decreases; and, fourth, because the running of the tests would be extremely difficult.

The method of running the tests which would come nearest to preserving conditions of constant propulsive efficiency thus seems to be out of the question. It would, of course, be possible to calculate propeller conditions for constant efficiency and run the tests under these conditions, but the errors introduced by such a method probably would not warrant the labor, and the accuracy would be not greatly in excess of that which would be obtained by running the tests at convenient propeller conditions and making such corrections to efficiency as are necessary in the reduction of the final data. However, the importance of running tests with the same propeller at nearly the same V/ND and blade angle is great. In some cases it may be desirable to run the propeller at constant tip speed for all tests in order to reduce the large and uncertain effect of tip speed upon propulsive efficiency. In other cases it may be advisable to install different propellers in order to avoid large deviations from the design condition. In cases of low tip speeds where the power is measured, it may be advisable to choose a propeller operating near peak efficiency and hold one blade-setting throughout the tests, because in such cases the propulsive efficiency will vary but little even for fairly large changes in air-speed. The best method of dealing with propeller efficiency will be determined by the conditions of each test and should be given special consideration during the planning of the tests.

If comparative tests are made at a constant indicated air-speed (for the same span and gross weight), the angle of attack of the airplane is the same. This may be desirable in certain cases, as when testing for the aerodynamic effect of a large change in non-induced drag, because it eliminates a possible error due to the change in equivalent flat-plate area with angle of attack. Generally, however, more important considerations will dictate the use of another method.

It will not usually be advisable to hold separately constant either the power required to overcome the induced or non-induced resistance except as these may result from running the tests at constant air-density and air-speed. This constant air-speed and density method is extremely useful in that it shows directly the equivalence of fairings and engine power (an excellent medium of aerodynamic evaluation), without opening the data to the suspicions that are often attached, by those who are not connected with the running of the tests, to results which must be interpreted by calculations. In practice, the running of tests at a constant-density altitude is quite feasible; and, as will be developed later, this limitation may be combined with either constant airplane speed or constant engine power.

The fifth condition which might be desirable to hold constant is the air density. Since the airplane, as well as the propeller, works strictly on a density basis, perhaps more can be accomplished by the attainment of this type of unformity between comparative tests than by any other method.

Sometimes it is desirable to test the speed which an airplane has at a constant engine power, because speed variations due to changed drag conditions can then be more easily isolated.

The relative merits of the different ways of running the tests depend to a great extent upon the kind of information desired and the character of the modifications made upon the airplane. Flight-test errors frequently can be evaluated by obtaining points for a curve, the fairing of which indicates the best average value. It is often possible to discover irregularities by curves, as, for instance, propeller unsuitability by a curve the points of which are at different blade-settings. Fig. 1 is an example of a curve of this type in which no irregularity is disclosed. Of all the variables which may be held constant for such a curve, density altitude probably is the most universally useful. This method can be combined readily with certain others.

As an illustration of the procedure required of the pilot for comparative tests in which several of the variables are held constant, one of the more complicated methods will be discussed. Consider the case of making the tests at one density altitude, of holding the propeller diameter and speed constant to avoid large changes in efficiency due to tip speed, and of running the tests at one engine power so that the effect of the airplane changes will be shown directly in maximum speeds, without its being necessary to make corrections to the test results. If this last requirement were unnecessary, the procedure would be much simplified, because the tests could be flown at constant density and engine speed, with various propeller settings, allowing both airplane speed and engine power to vary at will. The air speeds could then be

plotted against the measured engine powers (See Fig. 1, page 79) or corrected to a constant power.

Comparative Speed Tests at Constant Air Density and Engine Power—For the pilot to regulate both the density altitude and the brake horsepower in flight, he needs a number of charts to use in connection with his ordinary instruments. His first consideration is to find the density altitude at which the tests are to be made. The choice of this density altitude is governed by several things: first, it should be high enough so that, even with the maximum air-temperatures that are likely to be encountered during the tests, the terrain will not prevent flying at the high air-pressures thus made necessary; second, it should be high enough so that reasonably smooth air conditions can normally be expected. The use of a higher altitude than these two items require only involves unnecessary time in running the tests.

Fig. 2 was made from N. A. C. A. standard-altitude tables by plotting on coordinate paper pressure altitude versus air temperature for a constant-density altitude of 2000 ft. and then transforming the curve thus obtained into a straight-line chart for ease in reading. In practice, the instruments are calibrated before the charts are made so that the charts will show the instrument indicated values. In flight, the pilot reads the strut air-temperature and adjusts his pressure altitude by the altimeter until the temperature and altitude correspond, as shown by this chart. He is then at the correct density altitude.

Choosing Constant Engine Power Value

In choosing a constant value for the engine power to be used in comparative speed work, it is well to take a value somewhat below the maximum obtainable from the engine. There will then be a margin to take care of such losses in power as those due to high carbureter-intake air-temperatures.

To maintain a strictly constant engine power in comparative tests, the pilot would require charts taking into account humidity, back pressure, intake air-temperature and intake-manifold pressure. If the back-pressure correction is applied as a proportionate change in power dependent only upon the pressure of the air into which the engine exhausts, one chart could be constructed from the dynamometer engine-calibration to give the manifold pressure required with various back pressures and intake air-temperatures. A separate chart would be required to give the increment of vapor pressure (in terms of wet and dry-bulb temperatures) which must be added to the manifold pressure found from the first chart. When the humidity correction can be neglected, as is usual in test flying, the first chart would suffice.

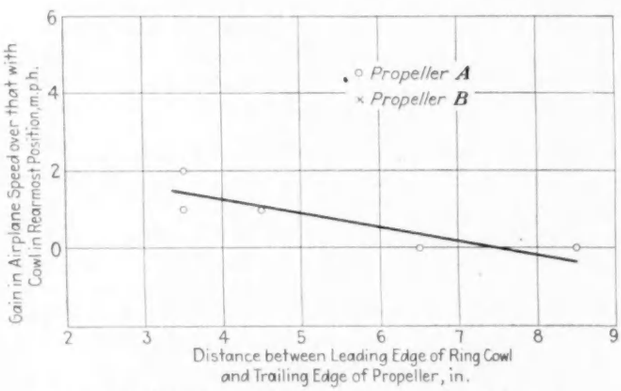


Fig. 4—Flight Data Obtained at Constant Air-Density and Constant Engine Speed and Power

Probably the small variation in airplane speed with ring-cowl position would not have been evident if the factors affecting maximum speed had not been carefully regulated.

Although the method just described results in a greater accuracy, it is possible to obtain satisfactory results by assuming the same back-pressure and humidity corrections for all the comparative tests. If this is done, the method is simplified and only one linear chart of carbureter-intake air-temperature versus intake-manifold pressure for a constant brake horsepower is necessary (See Fig. 3). This chart can easily be constructed with data from the dynamometer engine-calibration and the usual assumption that the brake horsepower is inversely proportional to the square root of the absolute temperature of the charge. It should be emphasized that, although the neglect of back pressure and humidity affects slightly the actual value of the brake horsepower, these two factors remain so nearly constant for comparative tests at a constant-density altitude that the brake horsepower is also essentially constant if the correction for intake air-temperature is made. The temperature effect upon power must always be measured when changes which affect the flow of air into the scoop have been made; it cannot ordinarily be neglected for other tests because of the atmospheric variation of temperature at a given density altitude. This becomes more serious as the time required for the tests increases.

In flight, the procedure necessary to find the intake-manifold pressure to give the desired engine power at constant density altitude is very simple. After ascertaining the correct density altitude, the airplane is flown level at somewhere near the correct throttle position for several minutes until the carbureter air-temperature has reached its maximum value. With this reading, the required manifold pressure can be found directly and the throttle set accordingly. If the engine speed is not correct, it may be brought to the proper value by changing the propeller pitch.

Consider now a particular example of using this method of controlling the major items affecting the maximum speed except the one whose effect is being tested. A certain airplane was equipped with a ring cowl which could be shifted a maximum of 5 in. fore and aft with relation to the engine. The effect of such a change was desired, as well as the location of a possible optimum position between the two extremes. In addition, the speed with two propellers was required. Fig. 4 shows that the change in speed due to ring-cowl position is slight but the trend is definite. Propeller B shows up as considerably better than propeller A. Throughout the tests the engine speed was kept at the constant predetermined value within ±10 r.p.m. For propeller A this necessitated one change of 10 min. in the pitch setting.

Conclusions

An attempt has been made in this paper to show that airplane flight-testing for maximum speed has a definite place as an aerodynamic instrument along with the wind-tunnel. Its outstanding advantage is the reproduction of actual flight conditions without any need for simulation. The use of the airplane as a laboratory has been greatly retarded by the difficulties and inaccuracies involved in calibrating its "instruments"—the propeller and the engine. The lack of reliable calibrations of both of these instruments leads, naturally, to a mistrust in their results. Knowledge of engine power is the first requisite, and it is thought that the method of manifold-

pressure calibration of the engine as previously outlined is an important step toward filling this need. The uncertainty regarding propulsive efficiency cannot be entirely removed, but it can be minimized by regulating its constituents as carefully as possible.

That class of tests whose purpose is to determine the comparative speeds of an airplane on which various modifications have been made is becoming increasingly important. Any one of a number of methods of running such tests may be desirable under certain circumstances, but in general the maintenance of a constant density-altitude in combination with a constant engine power or airplane speed is most satisfactory. Either of these conditions can readily be attained in flight by means of a few previously prepared charts. Above all, a full knowledge of all factors affecting the maximum speed of an airplane and a careful planning of the tests are necessary in order to secure valid flight-test results.

In conclusion, we wish to thank the engineers of the Pratt & Whitney Aircraft Co., who, having developed this type of engine calibration, cooperated in its application to flight testing, and to express our appreciation to C. H. Chatfield, assistant director of research of the United Aircraft & Transport Corp., under whose supervision some of these flight-test methods have been developed.

Airplanes Point Way for Motor Car

EVERY new development in engineering comes from the vision of new assumptions; the creation of new angles of attack on what are, perhaps, old problems. Often the fact that the problems are old ones and have been for so long a time solved in a certain way is the greatest detriment to progress. An old industry, like an old person, generally lacks a correct perspective on new things and the ability to see mistakes in its own work. Almost all old businesses are dumb, from the point of view of the outsider.

Only this year has the motor-car executive given any attention to aeronautic engineering, when somebody brought out the idea of streamlining a car, as one does an airplane or motorboat, so that the high speed might be improved. The first moves were made purely to improve appearance. In natural streamlining, the front shape does not amount to much, but the shape of the rear is very important. The designers started by rounding off the front end and calling it a streamlined car. The improvement was sufficiently noticeable to convince the motor-car group that there was something to aerodynamics after all, so they started building cars shaped like what they visualized as a streamlined form.

One cannot streamline an automobile like an airplane or a motorboat. With an airplane the air always comes directly from the front, never from the side. If it drifts with the wind, there is no pressure on the side; the wind is still from the front. We cannot run a motorboat across a river in the swiftest current and have the water do anything but streamline evenly on both sides; the water always comes from the front. Similarly, a bird, which flies through the air with the pressure always from the front, and a fish swimming in the water have this shape.

But if a motor-car is to be really streamlined while running on the ground with the wind blowing crosswise, it must be anything but fishy; it must be so streamlined that, whether the wind be from the side or the rear or quartering, the center of pressure of the air effort shall be at about the same spot for balance and the side-pressure areas shall be minimized. The analogies we have in nature are those of animals such as the turtle or crab, which live in currents of water and on the land also and whose bodies are streamlined in all directions but mostly fore and aft. This may not appeal much to the imagination, but it is none the less true.

The importance of air resistance is comparatively little at 30, 40 or 50 m.p.h., but from 50 m.p.h. up it becomes of major importance. Therefore, by all means let us streamline the bodies of our motor-cars—but technically, not by vision alone—and get all the advantage we can above 50 m.p.h. However, the speed from 0 to 50 m.p.h. represents 90 per cent of the use of the car, and improvements in this range are many times as important as streamlining.

In the actual mechanical performance below 50 m.p.h., the greatest single item of accomplishment is low weight per horsepower; so, while we are worrying about aerodynamics and streamlining, let us also pay attention to aviation structural analysis and powerplant design that we may cut down our weights, eliminate parts, decimate cost, multiply luxury, divide our operation cost by two or three and multiply again the available space within a given wheelbase and tread for which the purchaser has paid.

No good reason exists why a motor-car for five persons should weigh 1½ tons. The Ford tri-motored plane for transport work, weighing a total of 7 tons, accelerates from 0 to 70 m.p.h. in 10 sec. The little Sky Car on which I have been working for the last 18 months, with a 90-hp. engine, accelerates from 0 to 60 m.p.h. in 8 sec. Its weight empty is roundly 1200 lb., but it is an airplane with wings capable of supporting 6 tons, which would not be necessary if it were a motor-car. Take off the wings and put the same weight into the body—it already has an engine starter, 40 lb. of upholstery, four wheels with oversize tires and so on—and our motor-car acceleration problem is solved. If we build in quantity, it will be on a pound basis and with less than one-half the pounds of the present-day motor-car.

I do not expect automobile engineers to take this seriously, any more than the railroad men take the automobile engineers' statements seriously regarding their equipment. However, food for thought may be found in the fact that this already has been done in another industry and hence might have some influence worth studying. Certainly it is of more importance than hiring an aerodynamic wind-tunnel expert who knows nothing of motor-cars to do an airplane job on a road vehicle. Where aviation can help most, however, is in structural analysis and in the saving of weight-cost.—From a Summer Meeting paper by William B. Stout, S.A.E. Vice-President, Stout Engineering Laboratories, Detroit.

Operators Tell How to Fit Truck to Specific Job

IF the truck is to have its rightful place in the transportation field, F. I. Hardy, Boston consulting engineer, said last fall, truck manufacturers will have to do three things:

1. Sell the motor vehicle of the correct size, weight, horsepower and other characteristics for the service required;

2. Show the operator how to maintain that vehicle in good mechanical condition;

3. Show the operator the correct measure of efficiency in such a concise and simple way that it will be followed by the average operator.

His statements, which appeared on pages 436 and 437 of the November, 1932, S.A.E. Journal, stimulated a wealth of comment from motor vehicle operators all over the country. Some discussed the specific points mentioned above, others had much to say on other phases of his paper; some agreed with his ideas, others disagreed.

Following is a major part of the discussion which Mr. Hardy's paper, read originally at the Toronto transportation meeting last fall, brought from members:

J. M. ORR[1]:—The selection of a chassis for a particular application should be undertaken only after careful examination of operating requirements and consideration of the many factors that affect a choice.

Manufacturers are designing and building truck chassis to closer limits each year, permitting a much finer degree of selection with greater assurance of satisfactory service and lower costs than was possible a few years ago. To take advantage of this, buyers should have a thorough knowledge of the operating conditions and requirements to be met and an ability to evaluate properly the relative desirability of makes and models under consideration. A thorough study of conditions and requirements of particular applications has enabled us not only to choose a more satisfactory chassis but to effect sizable savings in many cases through the use of smaller units; lighter, stronger, and better-adapted bodies; the use of special instead of standard bodies and the like.

I do not believe that we can expect any manufacturer's representative or sales engineer to know as much about our business as we do; for without a definite enough picture of our requirements to permit his isolation of the model in his line best suited for our work, he is at a disadvantage. After we have been given various manufacturers' recommendations for a certain job, it is necessary to compare and study general fitness for the job, unit specifications, records of performance, first cost and probable operating costs to assure the best final selection. A motor-truck is a complex piece of mechanism that should not be chosen haphazardly. The several years of economical service that we expect to obtain from a vehicle justifies a careful purchase procedure.

Desirable Operating-Control Methods

Control records and statistics can be developed which will indicate the results being accomplished in comparison with past periods or with similar operations. A complete and suitable cost-accounting system, from which can be obtained the cost per mile, hour or ton-mile, the use factor, fuel economy and the like, is basically essential. Failures per 1000 miles or a similar unit of use and general percentage of vehicles out of service can be taken as indexes of maintenance efficiency and sufficiency. Control of materials and supplies inventories, cost of material handling, proportion of idle and non-productive labor to productive labor, careful supervision of shop operations and constant scrutiny of overhead expenses are some of the factors that many fleet owners or managers find helpful in obtaining their results.

A study of the number, causes and costs of vehicular accidents will yield information that will suggest proper corrective measures. An individual driver's accident record is helpful in correcting or weeding out accident-prone men. To this must be added driver training, an item of increasing importance. Every owner should know at first hand that his drivers are physically and mentally able to handle his vehicles and represent him creditably.

Each driver should be required to demonstrate satisfactory driving ability, a knowledge of local and State vehicle-code requirements and physical competence. An initial examination of drivers is insufficient. They should be periodically re-examined to assure continued driving ability and physical fitness. We inaugurated a vision and hearing examination for all of our 1300 drivers this year, with compulsory re-examination every two years. Briefly, our requirements are 75 to 85 per cent of normal acuity of vision with or without glasses, loss of not more than 40 deg. of peripheral vision, ability to distinguish color and no serious impediment of hearing. Examinations are conducted by our own physicians, who note the applicants' general physical condition at the same time.

Many of the men examined were unaware of deficiencies and have since taken corrective measures. Some drivers who were below standard and whose vision or hearing cannot be improved to meet our specifications have been denied driving privileges. Some, through their knowledge that they were below standard, have changed their driving habits to compensate therefor and have become careful, satisfactory drivers.

CLINTON BRETTELL[2]:—Unquestionably the truck manufacturer, under pressure of keen competition, has, in many in-

[This paper was printed in the November, 1932, issue of the S. A. E. JOURNAL, p. 436. The author is an industrial engineer, Boston.]

[1]M.S.A.E.—General manager, Equitable Auto Co., Pittsburgh.

[2]Superintendent of garages, R. H. Macy & Co., New York City.

stances, not only failed to urge the proper truck for the job in question but has even recommended something that he knew was unsuited to the job, simply because he felt that he would lose the order, on a price basis, if he did not meet the competition truck for truck. With conditions as they have been in the last several years, where an order must be secured at any price in many instances, that such a condition should have existed is not surprising. That it was not entirely universal, however, was illustrated in my own experience a short time ago, when one manufacturer held out very strongly for a certain design that his analysis of conditions led him to believe would give most satisfactory performance, although he had a competitive unit to sell for less money, but which, in his opinion, would not do the job. I hope that the manufacturers will go farther in this direction for the benefit of all concerned.

Ratio of Weight to Payload

The factor of ratio of weight of equipment to payload is unquestionably one of the utmost importance, although it has received little consideration in the past. In our operations we have had this very forcefully impressed upon us in attempting to carry larger and heavier loads that must be lifted out of a sub-basement, truck and load complete, by freight elevators of a very definite maximum capacity. To accomplish this, we had to adopt the lightest possible construction, both as to material and design. While striving toward this end, the possibility always exists of going too far and getting the type of equipment that will be continually breaking down or wearing out so rapidly as to require excessive maintenance and cost. A compromise must, therefore, be reached which will give the benefits of light weight combined with reasonable maintenance.

Wide Cost-Variations Explained

Mr. Hardy's explanation of the wide variation in cost per mile for maintenance, fuel and the like between apparently identical vehicles as due to the difference in the standards of maintenance in the two fleets undoubtedly accounts for some of the variation, but my opinion is that much of this is more than likely due to a variation in the daily mileage in which the two vehicles are operated. That the cost for the various items of maintenance and operation of a motor-vehicle do not vary appreciably as between a 25-mile day and a 50-mile day is a well-established fact; yet the divisor employed in determining the cost per mile is in one case double that of the other and hence the cost per mile in the first case is approximately one-half that of the second. While I do not intend to imply that the cost varies directly in proportion to the mileage, it has a very close relation thereto. I have made an exhaustive study along this line and have charted on a mileage basis for various types of car cost curves, fuel-consumption curves and the like which can be used in transposing from one mileage basis to another for comparative purposes. Without some such common basis, any comparison is impossible.

The type of records to be maintained in controlling fleet maintenance and operations should be as simple as possible and of a form that can readily be understood and employed by all those involved. No record should be prepared or kept *unless it is actually used,* either as an intermediate step toward further records or as a definite item of control. Records prepared and never used represent wasted effort and expense and serve to weaken the value of records in general in the minds of the organization members who are ordered to prepare them. They should be so tied in with master controls that their accuracy can be checked from time to time, because erroneous records lead to false conclusions and are worse than none.

Regarding the specific records mentioned, in our opinion a record of such daily operations as air pressures in tires, water in the radiators and the like would be unnecessary because a routine check of all these matters, either daily or for whatever period specified, would be the job of certain definite individuals in the organization. Whether or not they made a notation of conditions found would hardly make any difference as to whether proper conditions were maintained. A man who was slighting this work could easily write such a report without going near the vehicles. Records of work on more important items, carried out at longer time intervals, are necessary and desirable.

Whether a general inspection report or one covering certain definite items of regular inspection, such as brakes and wheel alignment, is the more desirable seems questionable. We incline to the latter system, particularly as the "safety" features of car maintenance are extremely important, because of the strict police regulations in the localities where we operate. Our general inspections would indicate only faults found which needed correction either immediately or within a short time. So that inspections shall be made uniformly at all of our garages and no important items overlooked, we have prepared a form for the guidance and instruction of those making the inspection.

Salesmen's Efforts Commended

H. V. Middleworth[3]:—My sympathy goes out to the many operators who, in days gone by, have purchased equipment that was not suitable for the work to be performed; but the days of "high-pressure salesmanship" in merchandizing motor-vehicle equipment have gone. The manufacturers of motor-vehicles long since realized the importance of placing the right equipment in the right place and have spent much engineering effort not only in anticipating the requirements of the operator but also in educating the salesmen so that they are fully capable of analyzing the needs of the customers and of recommending vehicles of the right size, weight, horsepower and the like to do the job effectively and economically. Many men in charge of fleets of motor-vehicles have, through years of experience, become educated to such an extent that they are often able to offer to the manufacturer valuable suggestions regarding the type of equipment best suited to specific operations.

I agree with Mr. Hardy that good mechanical upkeep is vitally essential to the successful and economical operation of motor-vehicles; but my opinion is that a comparison of costs per hour of service is preferable to cost per mile in measuring mechanical efficiency. My reason is that motor-vehicles operate under such varied conditions that cost per mile seems less significant. Vehicles operating in congested areas, where traffic delays are frequent and necessitate constant starting and stopping, cannot be compared with vehicles operating in sparsely settled areas over smooth roads and covering much greater distances.

B. S. Snowden[4]:—Mr. Hardy states that the manufacturers should be in a better position to advise operators of

[3]M.S.A.E.—Superintendent of garages, transportation department, Consolidated Gas Co. of New York, New York City.
[4]Transportation manager, General Ice Cream Corp., Schenectady, N. Y.

motor equipment as to the best types; but we work upon the policy that we will purchase our equipment from the manufacturer who makes the model which is best suited to our requirements and, in general, the manufacturers soon swing over to a model that we can use. I do not believe that very little variation exists in gas, oil and repair-part prices, because this is strictly a problem based on the operator's knowledge and also his cooperation and friendship with the vendors with whom he is doing business. Our contract prices on the same commodities might be considerably less than those stated by Mr. Hardy.

After the right vehicle is selected, states Mr. Hardy, consideration must be given to mechanical maintenance. In a few paragraphs beyond he states that inspection should be made after each 1000 miles. Our trucks are inspected daily because, in our work, if we let them go for 1000 miles, some repairs would be beyond the minor control and would be in the major classification.

Salesmen's Over-Statements Deplored

T. C. SMITH[5]:—Mr. Hardy emphasizes an important point in connection with the selection of motor-vehicle equipment which has to do with the information supplied to the purchaser by the vehicle manufacturer. Apparently the keen desire of the salesman to sell a truck often leads him to make statements that are not supported by the later service experience with the motor-vehicle. To build up a business with a fleet operator or in a community, the vehicles should be properly applied to the work they are to perform, and over-statements in selling the vehicles do not work toward this end. For instance, in discussing a situation possibly requiring a truck to carry a 2-ton load, a salesman, to illustrate the ruggedness of the unit that he is recommending for this job, will often cite cases in which his 2-ton trucks are operating daily between certain points and handling 4-ton loads without any trouble. For any salesman to make such a statement is a fallacy, because, either he has misapplied the truck that he sold for the 4-ton operation or he is attempting to sell too heavy a truck for the 2-ton operation.

I wonder, however, if too much emphasis may not be placed upon the responsibility of the truck company's salesmen to supply the proper truck to do a particular job, since we can hardly expect a salesman to know the necessary details of milk delivery, or merchandise delivery, public-utility operation and oil handling. While securing as much assistance as possible from the truck salesman is necessary, the operator should develop very definite information from his own experience so that he can compare truck equipment from the various manufacturers and intelligently select equipment suitable for his purposes.

As to motor-vehicle selection in general, two considerations exist which may not always lead in the same direction. This may result in the necessity for a compromise in favor of the more important of the two. While securing motor-vehicle equipment that will operate at the lowest cost per mile is desirable, in certain cases purchasing equipment that operates at a higher cost per mile may be more desirable if the service that this higher-cost truck can provide will be more valuable to the user.

For instance, if a truck operates with a gang of men, the truck cost may be only 10 or 15 per cent of the total daily cost of the complete outfit. Under these conditions the use of a slightly more powerful truck may be desirable, or one providing more suitable space for equipment to be carried, or tire equipment that will better negotiate the conditions encountered, or auxiliary power equipment to assist the men in loading and unloading the vehicle or in doing the work that they have to do. These factors, because of their aid in the performance of the entire crew throughout the years of life of the vehicle, may well save many times the relatively small increase in first cost and daily cost of the motor-vehicle unit. Of course we should make sure that the differential is as stated before the extra money is spent for the equipment. For a unit that may operate over a period of four to seven years, considerable thought should be given to its suitability in all respects to meet the conditions under which it will operate.

Buyers Have a Real Problem to Solve

J. F. WINCHESTER[6]:—Mr. Hardy suggests rightly that the selection of a vehicle for a given piece of work is highly important and places before the business man an idea that many of them have overlooked. He has brought out the point that manufacturers should be in a position to give sound advice but often have failed in this and, with adroitness, have covered up the error when selling the incorrect unit for a given job. Mistakes of this kind have been many in the past and can be laid directly at the door of high-powered salesmen whose commission and financial reward depend upon making as many sales as possible and who, regardless of the ultimate results to the user or to the salesman's own concern, will, if necessary to make a sale, meet the situation at hand with poor advice. Buyers have a real problem to solve in such a situation. These conditions, together with the other factors involved in highway transportation, call for the services of a first-class man who is capable of making an impartial decision after he has analyzed all models built by a given manufacturer or all makes on the market which can be used for a particular job.

I believe that loss of money to the user and manufacturer and the creation of many problems of national importance, such as safety, taxation, traffic regulations and highway maintenance, have been caused by failure of business interests to realize the importance of this phase of automotive transportation.

Salesmen Are Interested in Sales

J. R. BINGAMAN[7]:—Conceding that the major consideration is the selection of the vehicle that will best suit the particular need of the operator, I cannot, as an operator, agree that this selection can be made by any truck salesman. Experience has shown me that the average truck salesman is mainly interested in the sale, and not in the practical operation, of the particular vehicle he sells. If the average fleet operator left vehicle selection to the average salesman, the fleet would not suit the requirements and would not be economical to operate, mainly because each type of service to fleet owners is different, their conditions and requirements are vastly different, the average salesman is not conversant with such conditions and sells only on the basis of models, horsepower and average performance. Little, if any, consideration is given to chassis weight, width or turning radius. Until the time arrives when the salesmen employed have far greater training in practical operation, the selection of the

[5]M.S.A.E.—Engineer, automotive equipment and construction apparatus, American Telephone & Telegraph Co., New York City.
[6]M.S.A.E.—Supervisor of motor-vehicles, Standard Oil Co. of New Jersey, Newark, N. J.
[7]President, Bingaman Motor Express, Inc., West Reading, Pa.

desired vehicles must be left entirely to the practical operator.

But if the engineer of the motor-truck manufacturer should become interested in these problems and such salesmen would first consult with him and with the operator and if the engineer considers the problem confronting the particular operation and not some particular model of vehicle that the manufacturer desires to make popular, much good can be accomplished. In this connection, our experience has been sad. We have been encouraged by several manufacturers to purchase trucks that are excessive in weight, complicated in construction from a maintenance standpoint and that actually have violated the laws of the States through which they were to be operated.

The last point is specific because, in Pennsylvania, the law requires that the over-all width must be not greater than 96 in.; yet trucks are being sold that far exceed this width. After the truck is bought and paid for, the operator is arrested for having on the highway a truck that is not complying with the State law. No reference is made to width by the salesman nor by the engineer; but if the point is brought up by the prospective purchaser, he is told that it is immaterial and that the laws relative to width are not being enforced. But, if the law is enforced, the operator suffers, not the manufacturer. While we have never purchased a truck of this type, we have been approached many times and advised to purchase certain types that are beyond the allowed width and have been told that we had nothing to fear from the law. Such lack of cooperation should be corrected.

Operators' Difficulties with Manufacturers

In 1922 our company experienced great difficulty in persuading any leading company to build six-cylinder heavy-duty trucks, which we desired to assure uniform speed. Only after shopping around at that time could we induce a manufacturer to comply with our request. The request was not unreasonable, because the four-cylinder truck was not practical and soon passed out of the picture, but our company was branded as being eccentric at the time this manufacturer made the first two units for us. However, within six months from the completion of these units, the manufacturer announced to the entire Country that his company was producing six-cylinder trucks in all sizes. Why did not the engineers develop this demand instead of pouring cold water on their idea of satisfying a customer?

The same experience can be cited regarding our desire to reduce chassis weight. Our vision of the future Pennsylvania laws governing weight led us to seek a much lighter chassis, made of material that would assure stability and give us, within the State laws, the payload we required. The recent trend toward gross weight has proved that we made this move none too soon. When we consulted the leading truck manufacturers and asked for a chassis made of aluminum we were turned down, and only after exhaustive search could we secure such chassis. The price was a secondary consideration with us; but, by requiring aluminum, the gross weight was reduced 2800 lb. for the entire truck equipped with an armored cab. Had we not secured these chassis, we could not operate today over the interstate bridges. Here again the lack of cooperation between the set-in-a-groove manufacturers' engineers and the operator was marked.

[8] See *Commercial Car Journal*, July, 1932, p. 26.

Within the last six months we asked a leading manufacturer to construct similar trucks, using even lighter material. We were still looking toward prospective further reduction in legal gross-weight, but we were told that, even if our trucks effected a considerable reduction in gross weight and were performing efficiently, the manufacturer was not convinced that a market existed for such trucks and would not deviate from his standard-construction practices. Naturally, we had to go elsewhere to make our purchase.

Considering the present national activities against the truck and with the present laws restricting weights, we cannot conceive why more attention is not given to the reduction of weight of the standard units made by the truck manufacturer and of that of other units not made by the truck manufacturer but which are used in the finished chassis. I agree that the main object of the manufacturer is to sell trucks and that not only he but also the purchaser must be educated as to simplicity of construction, ease of maintenance and operation, rather than in specified models and performance. By this I mean the making of all parts so that they can be serviced with the least amount of mechanical interference.

List Prices of Trucks Critized

As a point for argument, I bring to attention what I consider to be the major factor in this problem of motor-truck salesmanship. I know of no other large and expensive piece of equipment having a list price so inflated that it is merely an approach price and is not intended to be the final price. This is caused by the damnable factor of need for consideration of the used unit. Disposition of used units constitutes a boomerang to the manufacturer and to the buyer. If a sale is to be made, excessive allowance must be made for a worn-out piece of equipment, and this immediately becomes a liability to the manufacturer. He has sacrificed a just profit in granting an excessive trade-in price. To get out of the red, he must sell this junk. Only one market exists for the particular used truck; that is, right back in the line for which it is best suited, such as dump, express or contract work. Therefore he must sell it for a nominal price to anyone who wishes to enter such a business. So a multitude of "chiseling" operators in all lines is created who have no large real investment and who undermine the business of operators who buy new equipment. This condition is not only destructive to standard established businesses but constitutes a rebound to the detriment of the manufacturers. As stated in my article on Inflated List Prices Should Be Exploded,[8] the solution is not alone the burden of the manufacturer but of the operator as well; that is, to eliminate the inflated list price of the chassis, to accept no trade-ins except at scrap prices, and to destroy immediately each trade-in. This is the practice in other lines. It keeps from the field the worn-out units, places the manufacturer on a higher plane and relieves the operator from chiseling competition that thrives on the follies of both the operator and the manufacturer.

The remainder of Mr. Hardy's paper is practical and correct. To secure the most effective operation at the least cost, daily inspections and periodic overhaulings must be made, depending on conditions of service, climate and load. Much depends upon the type of men employed to operate the equipment, and the present trend of hiring cheapness instead of efficiency will tend only to raise the cost of operation. A driver is entitled to a fair wage in consideration of

the skill required to serve his employer efficiently and protect other users of the highways.

W. F. Banks[9]—Mr. Hardy's paper seems to me to be an appeal to the motor-vehicle manufacturers for a primary schooling system of management. In this appeal he has pointed out the fundamental weakness of the industry as a whole; that is, too many operators do not know what they need, how to service what they have or how to measure the value of the service performed. In my opinion an intelligence test should be applied before the business is allowed to start; responsibility and ability should be requirements for the right of franchise. Otherwise, motor transportation will never become stabilized and reach the heights of big business.

To solve the problem of control, the following procedure should be followed:

(1) Put intelligent men in the key positions: management, selling, operating and maintenance
(2) Provide the proper tools for exercising intelligent control
(3) Establish job responsibilities and measure man values by results
(4) Hold executive committee meetings regularly
(5) Analyze operating results monthly, particularly dollar-and-cents results, and discuss them with department heads

In outlining these major specifications I do not point to the larger operations alone but also to the organization necessary to establish responsibility through intelligent management.

As to item (1), no matter how small the operation is, intelligent men can and should be placed in key positions. If properly placed, the combined knowledge of their accumulated experience will save more money than all the other systems that can be devised for the same purpose. Given a problem, they will find a solution, each from his own viewpoint, but so coordinated as to assure the proper functioning of every activity.

Regarding item (2), all business results are eventually measured in dollars and cents. Consequently, an adequate cost system provides the only real tools for intelligent control. While results down the line of activities may be measured in other terms and provide a medium for comparison, the fact remains that the key man should have an intimate knowledge of the cost of the various detailed activities over which he exercises daily control if he is expected to use his best judgment at all times. Concerning physical control of operations, the most useful measure of performance on a given job is usually the unit used for the basis of compensation, whether it be pounds, packages or gallons. This seems to be the only method by which the operating and sales departments can be brought to a mutual basis of understanding.

Analyzing item (3), any man who is expected to use his intelligence must be given a certain amount of authority, and there can be no real authority without responsibility; further, without having definite responsibilities, human nature too readily disclaims failures and claims successes. Whether it be merely cleaning a garage or directing the entire operation, the responsibility for all activities connected with the particular job should be very definitely placed and understood.

Considering item (4), any successful cooperative effort is the result of a mutual understanding of one another's problems. No better way of producing this understanding exists than getting a group of key men together regularly and inviting frank discussions. Further, this provides the quickest and best means for formulating policies and securing their prompt execution.

Analyzing results monthly, item (5), may be purely a management function; but, at the same time, department heads should be required to explain or defend the costs for which they are responsible. While they will make their own interpretations and comparisons, they should be shown the effects of their activities on the business as a whole.

I have covered the subject of control in the broad sense because each department, if considered in detail, would provide in itself a subject for discussion.

Changing Models Too Often Creates Difficulties

H. E. Hildebrand[10]:—Three things that the manufacturer should do for the motor-truck, to enable it to take its rightful place in the transportation field, are stated by Mr. Hardy. My belief is that a fourth item should be added; namely, that the manufacturer should not change models too often and thus make obtaining repair parts difficult. When a truck is purchased to operate for a predetermined number of years, the operator should be able to obtain spare parts readily throughout the life of that truck. Waiting for factory shipment of parts is costly.

Trucks are not replaced as frequently as passenger cars, yet many manufacturers produce a new truck model whenever a new passenger-car model is placed on the market. I believe that the only justification for a change in truck-parts design is the introduction of more efficient or better-wearing units. If possible, such units should be designed to fit the existing trucks. This would not, I believe, have a tendency to decrease truck sales, because the truck operator usually continues to operate his old truck as long as he can economically do so and in spite of the fact that a new model is on the market. A change in external appearance or body lines need not affect the working parts of the truck nor the interchangeability of such truck parts.

[9] M.S.A.E.—President and director, Motor Haulage Co., Inc., Brooklyn, N. Y.

[10] M.S.A.E.—Director of engineering, Continental Baking Co., New York City.

Errors in C. F. Taylor Paper

An error occurred inadvertently in redrawing the engine-indicator diagram shown as Fig. 3 in the paper by C. F. Taylor entitled Bending Moments in the Master Rod of a Radial Aircraft Engine, published in the S.A.E. Journal for December, 1932, p. 489. In the scale of pressure in pounds per square inch, 0 should be 15 and −100 should be 0. The lower loop is exaggerated and the scale below the 15-lb. gage-line changes. A gage minus value of the magnitude shown by the diagram as printed is, of course, impossible.

Typographical errors occurred also in the equations on p. 492. The point was misplaced in the quotient in the following equation for the J-5 engine, making it read 0.064 instead of 0.64. The correct equation is

$$(2.75 \times 2.05) / (10.87 - 2.05) = 0.64$$

In equation (1) on the same page, the symbol M_{max} was misplaced; it should have preceded the first equals sign instead of the second, so that the equation would read

$$M_{max} = (12{,}250 / 0.64)\ (b^2 / 20.3)\ (R_r / L - r)$$
$$= 944\ (b^2\ Rr / L - r)$$

Future Clutch Progress Charted from Design A-B-C's

By E. E. Wemp

MOST of us can still remember the time when, in a process mutually painful to all concerned, our parents laboriously taught us our elementary A-B-C's. If we gave the matter any consideration at the time, we undoubtedly were happy in the thought that *that* particular job was over with for all time. Later, with broadening judgment and widening experience, we found that nothing could be farther from the truth.

Progress is an exacting master. It demands that for each new stage of development there must be a corresponding set of standards—a set of A-B-C's, if you please, formulated to fit the new conditions imposed by that development. For this reason we often find ourselves facing a new situation—a new stage of development—and are surprised to realize that the old A-B-C's, which answered so well as applied to the old standards, must be supplemented by a new set devised to fit the new stage of development.

This principle may be observed in the progress of our automotive industry, in which you are so vitally interested, and, as well, in all of the allied branches of which it is composed. We therefore see the reflection of this same principle in looking back over the history of automotive clutches.

There have been four distinct stages in the types of clutches used in automotive vehicles up to the present time. These four undoubtedly are familiar to all of you, and they form a very interesting history on the subject from which many valuable lessons may be learned. However, the purpose of this paper is to attempt to feel the current pulse of the industry with the view of determining what we may expect to see in the way of clutches in the *next* stage, which, we believe, like our old friend prosperity, is just around the corner. With this in mind, we will deal very briefly with the stages which have gone before, being content with merely classifying them in their chronological order.

(1) The stage of the cone clutch type
(2) The stage of the multiple disc, metal-to-metal, running-in-oil type
(3) The stage of the multiple disc, dry plate type
(4) The stage of the lever release, single and two plate type

These types vary widely in design, materials used in their construction, operating characteristics, dependability and serviceability, and associated with each type is its own peculiar set of A-B-C's which had to be learned and discarded in turn as each epoch flourished and passed on.

The first three stages are now a matter of history, as practically all of the clutches of today are of the lever release, single or two plate type. This type made its appearance in about 1915, has grown in popular favor steadily and for approximately the last three years has been in almost universal use in the automotive field.

Notwithstanding the truth of the foregoing statement, there has been a great deal of development work in the clutch field in the last few years, the result of which may introduce a fifth epoch in clutches and force us to learn another new set of A-B-C's as applied to the clutch art.

This development apparently is the result of an insistent demand that automobiles be made easier to operate, with less labor on the part of the driver, and that functions which have in the past been performed by the hand or foot be made automatic. Naturally, this brings the clutch into the picture, since almost from the advent of the automobile the driver's left foot has been more or less continuously occupied with the operation of the clutch pedal.

As is usually the case, this development work has attacked the problem from widely varying angles, and from these varying angles of approach will undoubtedly appear a solution of the problem which will become a part of our new A-B-C's in clutch design.

Reviewing the known activities in the clutch-development field, it would appear that the various angles of approach to the problem may very well be represented by the letters themselves of the new A-B-C's we must learn. With this in mind:

A—May well represent the subject of automatic clutches
B—Basic improvements in clutches of the lever release single and two plate type
C—Clutch control, through external means, of conventional clutches

In engineering circles it is often considered good practice to "put the cart before the horse"; so we are exercising this engineering license in placing the subject B at the head of the list for first consideration.

This type of clutch, in this class, as stated before, has been in use since about 1915, and has gradually replaced its immediate predecessor, the multiple-disc dry-plate clutch, to the extent that it is now in almost universal use. Naturally, there

[Mr. Wemp is engineering counsel of the Long Manufacturing Co. This paper was read at the 1933 Annual Meeting of the Society.]

Summary

FIRST consideration is given by the author to basic improvements in clutches of the lever-release single-plate and to those of the two-plate types. He emphasizes that the severity of clutch service has increased very materially in the last few years and that the increased clutch duty of today is further augmented by the car manufacturer in providing cars having greater acceleration and higher torque, particularly at the higher speeds and usually without a proportionate increase in clutch size.

Developments along logical lines which have resulted in improvements in design are cited as being (a) the design of the driven disc and the selection of facings, to produce improved engagement and greater life; (b) design of the cover-plate assembly to permit higher spring pressure with less retracting movement of the pressure plate; and better selection of facing and pressure-plate materials to reduce facing wear and pressure-plate distortion or scoring.

In discussing automatic clutches, comments are made on those of the centrifugal type, on manual operation at all speeds, on conversion of a clutch from an automatic to a conventional type under certain conditions, and on free-wheeling. Manufacturing problems, typical designs of centrifugal clutches, and fluid couplings are treated also.

Clutch control means the control of a conventional type of clutch through an external agency such as the vacuum control, as distinguished from those in which the automatic action of engagement or disengagement is inherent in the design of the clutch proper. The vacuum-controlled clutch is then described and commented upon.

have been many improvements, not only in design but also in the choice of materials and workmanship.

It may be well to point out that the severity of clutch service has increased very materially in the last few years. This has been brought about by the surprisingly successful activities of the traffic light salesman, the rapidly increasing number of stop streets without traffic lights, and the increasing number of automobiles used on the highways. These factors have had the effect of increasing the number of stops per mile in cross-country driving by at least 5 per cent, while in traffic driving it is proportionately greater.

Clutch Work Increased

The increased clutch duty of today is further augmented because the car manufacturer is providing the public with cars having greater acceleration and higher torque, particularly at the higher speeds, and usually without a proportionate increase in clutch size. The trend in design has been toward a lower center of gravity and, in order not to sacrifice road clearance, bell-housings have been made smaller in diameter for comparable engine sizes, further limiting the available clutch size. The purchasing agent, too, has been close to the picture to see that *nothing* about the clutch increased without first seeing him. In spite of these handicaps, we believe it can be truthfully said that clutch progress has kept pace with the rest of the car development.

As a practical example of the increased rated capacity of a present day clutch over one of similar facing diameter and area of, say, four years ago, we have one of our own designs in mind which was rated at that time at 190 ft.-lb. torque; the same size now has a rating of 260 ft.-lb., an increase of 36 per cent. This increase in capacity has not just been taken out of the factor of safety of the clutch, but is rather the result of considerable development along logical lines and may be summarized as follows:

(1) Design of driven disc and selection of facings, to produce improved engagement and greater life
(2) Design of cover-plate assembly to permit of higher spring pressures with less retracting movement of the pressure plate
(3) Better selection of facing and pressure-plate materials to reduce facing wear and pressure-plate distortion or scoring

It was found that the design of the driven disc itself has a considerable influence upon facing life. A driven-disc design to give maximum facing life should present a full-surface contact between the facing and its adjacent driving disc throughout the engagement period. The flexible element introduced into the design to permit of yieldability and thereby soften engagement should be effective over as great an area of the facing as possible. In other words, small localized high-pressure areas are to be avoided.

As regards facings, our present conclusion is that density in a facing is necessary for the longest life. For this reason we are recommending a woven type of facing in installations where a low wear-factor is essential and where the increased price of the woven type of facing can be afforded.

The driven member shown in Fig. 1 is an example of one of the newer types and is made by the Borg & Beck Co. of Chicago.

The rim of the disc is divided into segments and each segment is formed to a definite shape. That portion of the segment included between lines 2-2 forms a triangle flat land. At the lines 2-2 both ends of the segment are bent upwardly at a slight angle and at lines 3-3 is again brought back to a flat plane forming the rectangular flat lands as indicated by the shaded lines. The lugs "E" are likewise bent upward in the same direction but not to as great an extent as the ends of the segments. In assembly, the front facing is attached to the forward side of the disc, by means of the rivets "F," and the facing lies directly on the flat

triangular lands on the convex side of the segments. The rear facing is riveted to the rear side of the disc by means of the rivets "D" which go through suitable holes in the upturned lugs "E." It will be seen that the rear facing is drawn snugly against the small rectangular lands at the ends of the segments. The two facings are thus mounted in flexible relationship with each other due to the resistance to flexing of the distorted segment ends and the upturned lugs. This construction presents a substantially full surface contact for purposes of engagement.

A driven member of our own design is shown in the accompanying Fig. 2. It comprises a flat disc "C" and six spring steel cushion segments "D." These segments are provided with a flat central land with holes for riveting the segment to the flat disc by means of the rivets "E." They also incorporate the two raised lands per segments with holes in these lands for riveting the segment to the rear facing by means of the rivets "F."

In assembly, the front facing is attached to the flat disc by means of the rivets "G." The segments are riveted in a fixture to the rear facing by the rivets "F." This makes a subassembly of the rear facing and segments. This subassembly is then attached to the flat disc "C" by means of the rivets "E." It will be seen that the two facings are mounted independently of each other but in flexible relationship for engagement purposes.

Interesting Design Feature

One of the interesting features of this design lies in the possible variations in shaping the flexible lands of the segments. It will be noted that both ends of an individual segment comprise beams supported at both ends and loaded in the middle. The resistance of the segment to flattening out can therefore be varied between its inner and outer radii. A little thought will disclose that this loading condition can be varied in the design to give either a uniform unit pressure across the width of the facing during engagement or a uniform torque capacity across the width of the facing, or any combination of the two which may be desirable. The shape of the segment shown is designed for a 10 per cent departure from a true uniform torque capacity across the width of the facing in favor of lowering the unit pressure at the inner edge.

The coverplate assembly shown in Fig. 3 is rather typical of the newer designs. Note the heavy section of the pressure plate, for the dual purpose of providing thermal capacity and the reduction of springing. Also note the needle bearing mountings of the release levers. The levers are made from forgings and are heat treated. Their design and number provide the necessary stiffness to reduce springing and lost motion to a minimum. This assembly is designed to permit of about 2000 lbs. total spring pressure, giving a capacity of 330 ft.-lbs. torque. An installation of this type requires that the flexing movement of the driven member unit as well as the runout be held to a minimum, in order to provide a high clutch pedal ratio and low clutch pedal pressure with the average amount of clutch pedal throw. One installation of this type is used in connection with a 285 ft.-lb. motor and, with a total clutch pedal stroke of 6½ in., has a pedal pressure at the releasing point of 27 lb. The total spring pressure on this particular job is 1850 lb. Other details of interest are the pressure springs enclosed in spring cups to minimize centrifugal throw of the springs at high speed, the heat insulation buttons between the springs and their mounting to the pressure plate. Another detail of interest is the 16-spline hub, designed to provide a maximum of bearing surface for its length.

Considerable work has been done in the study of friction materials and their effects upon pressure plates. The objective of this research was to discover, if possible, the relationship between coefficient of friction of the facing and its effect upon pressure plates with regard to warpage, breakage, heat checks, burned spots and metal movement. It is probably too early to attempt definite conclusions as a result of this research. However, there are certain characteristics which are apparent and which may be of general interest.

a. Generally speaking, the socalled molded facings are harder on pressure plate surfaces than are the woven types of facing.

b. The facings with the higher coefficient of friction are generally more severe in action on the pressure plate surface than ones of lower coefficient.

c. Full surface contact of the facing during engagement greatly reduces the evils of warpage, breakage, heat checks, etc.

d. Certain types of woven facings showing a lower coefficient of friction on the testing machine than some of the molded types will produce a stall at wide open throttle in a car in a shorter interval of time than molded facings with an apparently higher coefficient of friction. No good explanation of this fact is known at the present time.

In conjunction with the work on friction facings and their effect on pressure plates, the material from which pressure plates are made has been under observation and test.

"The Four Horsemen" of pressure plates may be classified as breakage, warpage, burned spots, and metal movement.

Breakage is, of course, the most serious offender, but unfortunately cannot be considered by itself. The use of steel, particularly a high carbon content steel, would naturally eliminate the trouble from breakage. This cannot be done, however, without running into about as serious a trouble from warpage. By warpage is meant the tendency of the pressure plate to become coned, the concave side of the cone always being on the side adjacent the facings.

A high carbon steel pressure plate has a very pronounced tendency toward warpage. Eliminating steel then as a possible material, the best results are obtained from some of the new high tensile irons. The use of these materials greatly diminishes the dangers of breakage and their tendency to warp is quite favorable. It has been quite clearly established

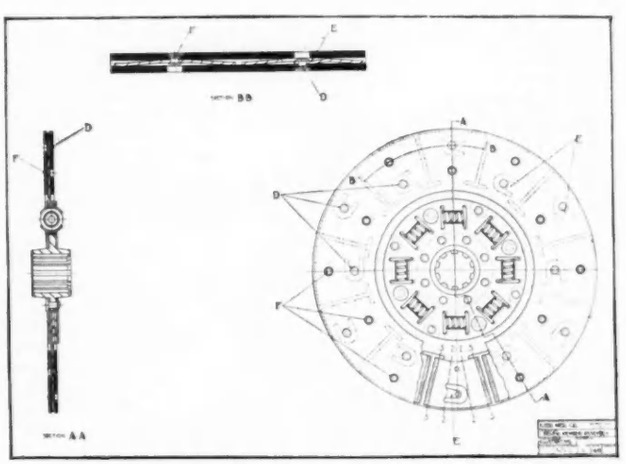


Fig. 1—Borg & Beck Driven Member Shown Here Is One of Newer Types

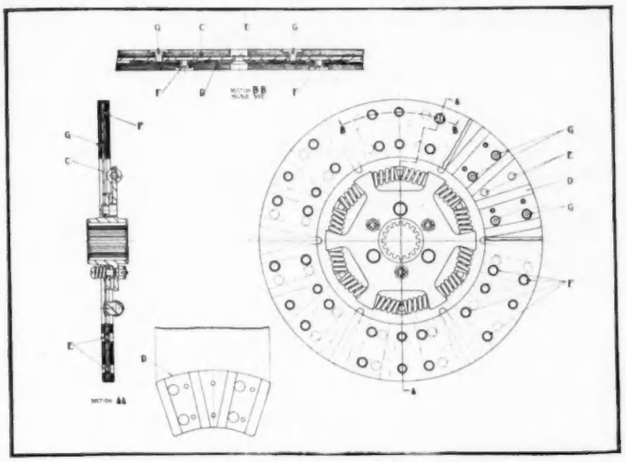


Fig. 2—Driven Member of Long Design

that anything which may be done to reduce the tendency toward burned spots and metal movement will also aid materially in the reduction of warpage.

As stated before, it has been found that the design of the driven member is quite intimately tied in with these conditions. A driven member presenting a full surface contact upon engagement does much to defeat the four evils of breakage, warpage, burned spots and metal movement.

Given a driven disc presenting other than full surface contact during engagement, woven facings will generally cause less damage than molded facings. In other words, the benefit to be gained by the use of woven as against molded facings, insofar as pressure plate conditions are concerned, is much more apparent if used in connection with a type of driven disc producing a rolling-in type of engagement.

Any type of driven disc which causes an initial contact at the inner edge of the pressure plate is to be avoided because of the localized rapid build up of temperature at the inner edge of the pressure plate, which in connection with the inevitable expansion and the low capacity of cast iron to resist tension strains, will too frequently result in breakage.

It is interesting to note that any method used in the driven disc to help the evils pressure plates seem heir to, has the additional benefit of reducing facing wear. This is probably due to the fact that if metal movement of the pressure plate can be eliminated, there are many less metal particles which are picked up and imbedded in the friction material to act as an abrasive and to cause further wear. In other words, anything which may be done to cause the pressure plate to remain smooth, flat and free from burned spots or metal movement will in turn react favorably in obtaining a much lower wear rate of the friction material.

In passing from the subject of conventional clutches of today, it cannot be amiss just to mention a few of the improvements in materials and manufacture which have helped to improve the present day product.

Driven discs are almost universally made from high carbon content stock. Most of them are heat treated to a spring temper and will stand considerable heat without distortion.

Friction facings are made more uniformly as to composition, are manufactured to much closer limits of uniform size and are ground to very close limits of parallelism on precision machinery. On molded facings a .0015 in. limit of parallelism is now a commercial tolerance.

Most pressure plates are made from one of the high tensile grades of cast iron, air furnace iron, or electric furnace iron and are usually finish ground on the engaging surface. In many cases the pressure plate is balanced before assembly to the coverplate.

The final balance of clutches has been greatly improved. Our own practice demands a limit of .2 oz. in. of unbalance as the clutch is taken from the balancing machine, and I believe this will check closely with the limits of other reputable manufacturers.

So much for clutches of the present day. We will now go back to the Alpha of the new A-B-C's we must learn.

Automatic Clutches

For the purpose of this article, an automatic clutch is one which inherently is always released at idling speed and which automatically engages with a speeding up of the motor. This must not be confused with the type where a conventional clutch is controlled by some external means to give the same action as outlined above. The latter type will be discussed under the heading of "Clutch Control."

Of the inherently automatic clutches there are two types which have been developed to the practical standpoint and are of the most interest to the automotive industry. These two are the centrifugal clutch and the fluid coupling, known more commonly as the fluid flywheel.

Centrifugal Clutches

This type of clutch, on which a great deal of interest is now centered, is in reality an old one in the clutch art. As far back as 1907 the Sturtevant brothers evidently gave a great deal of thought to this subject. The records of the patent office disclose that their conception of the problems involved in the practical application of a centrifugal type clutch to automobile practice was nearly as complete and comprehensive as that of today. These two pioneers in this art were unfortunate in being ahead of their day, and no matter how far the centrifugal clutch may be advanced in the future, the automotive industry as a whole will always owe a debt of gratitude to these brothers for the vision which they had beyond their own day.

A centrifugal type of clutch reduced to its elementary form is indeed a simple piece of mechanism. It comprises a system of weights so mounted that variations in motor speed

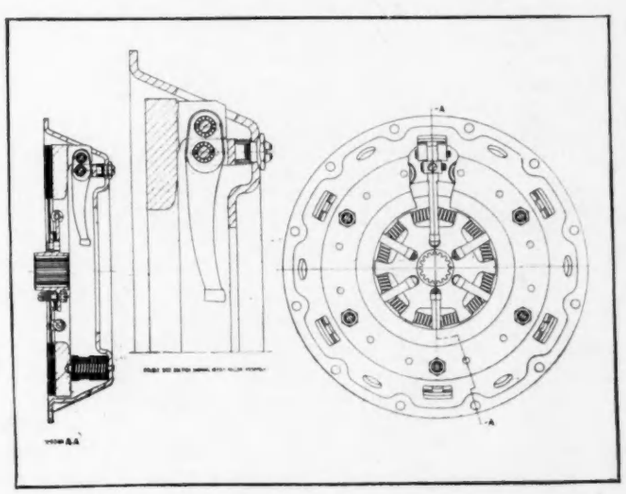


Fig. 3—Cover Plate Assembly, Typical of Newer Designs

will, through centrifugal force, effect movement of a pressure plate to increase or decrease pressure between the pressure plate and a suitable driven member.

Such a mechanism will not answer all of the requirements of a device for use in an automotive vehicle. To obtain a clearer understanding of the various requirements involved it may be well to list them in order.

1. The clutch must always be released at a pre-determined motor speed, known as the idling speed. It must engage initially at a motor speed from 50-100 r.p.m. above the idling speed. To avoid excessive slippage, the clutch should be fully engaged at a motor speed of from 900-1000 r.p.m. These figures are based on a motor idle speed of 475-500 r.p.m.
2. The clutch must be manually operable at all speeds.
3. The installation must include a conversion system for changing the automatic clutch to a conventional one in order to satisfy certain conditions to be discussed later.
4. To obtain the maximum benefit from an automatic clutch of this type it should be used in conjunction with a free-wheeling element in the transmission line.

With these four essential requirements in mind we will discuss some of the practical problems involved in such an installation.

The first requirements of release at a pre-determined speed and initial engagement some 50-100 r.p.m. above that speed, introduce the first serious problem. The speed range between release and initial engagement is necessarily small and this small speed range between the two distinct actions of either clean release or initial engagement makes it imperative that the frictional elements of the centrifugal system be reduced to a minimum.

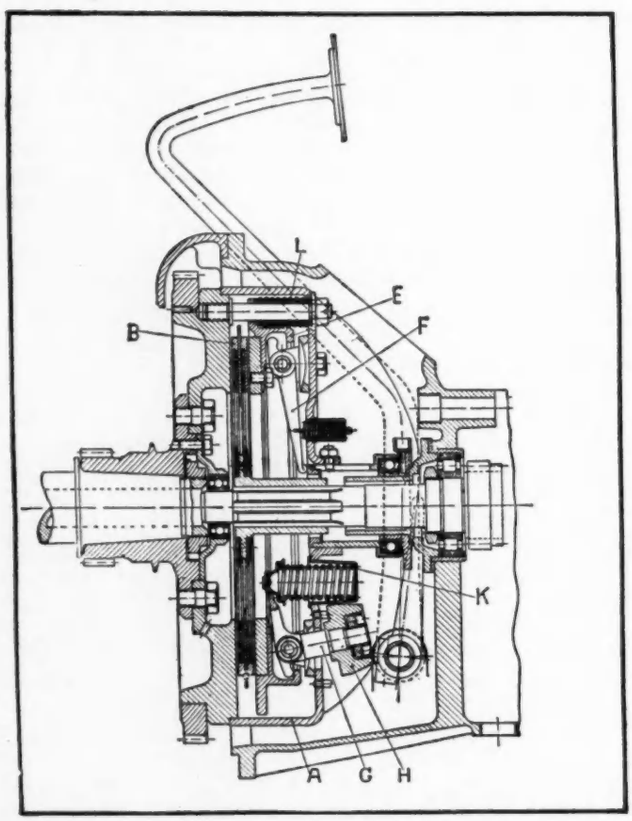


Fig. 4—N.A.G. Protos Centrifugal Clutch. It Is Manufactured in Berlin

The problem is further complicated by the fact that a clutch must be either a wet clutch or a dry one. With our friction facings of today, there is no middle ground. The preponderance of opinion being in favor of a dry clutch, we will assume that centrifugal clutch must be dry. The mounting of the centrifugal system, then, must be such that it be practically frictionless at all times, that it be assembled without lubricant and that it operate indefinitely without lubrication. To satisfy these exacting conditions, it would appear that the centrifugal system must be mounted on balls or rollers, or operate on knife edge fulcrums. In our experience, any mounting requiring a sliding action between the metallic surfaces will not answer the requirements and will interfere either with clean release or will change the r.p.m. spread between release and initial engagement. Fortunately the movement of the centrifugal members is small and the velocity of their movements is low, thus lending themselves to a ball, roller, or knife edge mounting without lubrication being necessary to their long continued action without undue friction.

Manual Operation

Several conditions arise making it necessary that the clutch may be operated manually at all speeds. The first and probably the most important one comes from the fact that in cold weather a motor will not run at its normal idle speed until it has an opportunity to warm up. During this warming up period it is impossible to obtain automatic clutch release, since the motor is then turning over at a speed considerably higher than its normal idle speed and the centrifugal system is causing engagement. To operate the car during this period it is necessary to operate the clutch manually in the conventional manner. Considerable work has and is being done to lower the time interval of the warming up period so that this undesirable feature should be improved as time goes on. Occasionally it may be necessary to declutch manually at a high engine speed to take advantage of flywheel inertia in jumping a car out of a bad hole while in low gear. In any event, the clutch design should be such that in declutching at high engine speeds, the foot need overcome only the normal pressure spring load and in no wise have to overcome the centrifugal force of the weight system, which at high engine speeds is enormous.

Practically all of the later centrifugal clutch designs are built around the principle that the reaction to the load applied to the pressure plate, by the centrifugal system, is taken through the main pressure springs of the clutch. As centrifugal force builds up with increased engine speed, the pressure springs are compressed, thus allowing the weights to move outwardly until their movement is arrested by a positive stop. When this point is reached, a further increase of speed does not result in an increased torque because the weights are against the positive stop and the torque capacity of the clutch is measured by the pressure spring load at that point.

It is probably unnecessary to state that the centrifugal weights work against a system of retractor springs, which may be arranged radially, axially, or in a combination of both, the function of the retractor spring system being to overcome the action of centrifugal force of the weights so that they are held to their innermost position at motor idle speeds to obtain a condition of automatic release at that speed.

Centrifugal clutches are provided with a lever releasing system usually similar to those used in conventional clutches, for the purpose of manually retracting the pressure plate for declutching when the clutch pedal is depressed.

Conversion System

The conversion system, whose function is to convert the clutch from an automatic to a conventional type under certain conditions, is a very interesting and important feature of any good design. The necessity for such a conversion system is at least two-fold.

First—It is often necessary to turn the motor over by either towing or pushing the car. A low storage battery in winter weather probably furnishes the most frequent occasion for this procedure. Unless the centrifugal clutch installation provides such a conversion system, the car can be used only to turn the engine over when the motor is running at a speed above the normal idle speed. A dead motor in that case cannot be started by the car at all.

Second—In many hilly localities it is necessary legally to park a car in gear so as to take advantage of the motor as a braking means. Again, without a conversion system, this would be impossible since normally a centrifugal clutch is definitely disengaged at all speeds from zero up to and a little over the normal idle speed.

It will thus be seen that such a conversion system is both a practical and legal necessity.

There appear to be at least two methods for accomplishing this necessary function. The first to be described was brought out by the Powerflo Company, and consisted of a two piece release sleeve mounted on the customary extension of the transmission front bearing cap.

This sleeve is arranged with interacting cam surfaces, so that a partial rotation of one of the cam members causes the other cam member, which carries the throwout bearing, to move axially forward or back, depending, of course, on the direction of rotation of the first cam member. A bowden wire connection with a dash control button permits the operator to move the first cam member at will so as to either lengthen or shorten the effective release sleeve length.

When the release sleeve is in its extended position, the throwout bearing on the sleeve arrests the rearward travel of the release levers, which in turn positions the pressure plate so as to effect automatic release of the clutch at normal idle speed of the motor.

When it is desired to change the clutch to a conventional one, the operator by moving the dash control button contracts the sleeve to its shortened position. This in turn withdraws the throwout bearing from its arresting position of the release levers and the pressure springs then may force the pressure plate forward into an engaged position with the driven member.

When this is done the clutch is a conventional one and can be used in the normal way for towing, pushing, or parking purposes. To change it back to an automatic position the process of operation must, of course, be reversed.

In the vacuum conversion system as developed by our company, the release sleeve arrangement may be similar to the one just previously described. That is, it may consist of a similar two piece release sleeve with interacting face cams, the one cam member rotatably mounted, the other cam member, which carries the throwout bearing, fixed against rotation but capable of being extended or contracted through the action of the rotatable cam member.

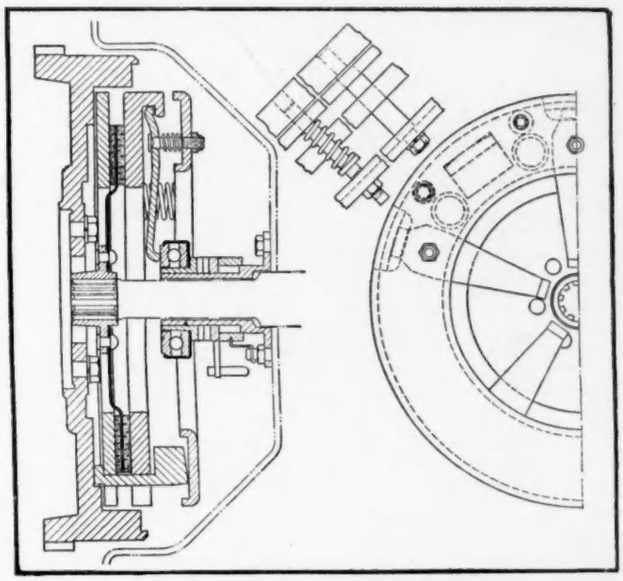


Fig. 5—The Powerflo Automatic Clutch

A suitable vacuum cylinder is attached to the side of the clutch bell housing and the piston or diaphragm of the cylinder is operably attached to the rotatable cam member. A small tubular connection between the vacuum cylinder and the intake manifold completes the working arrangement.

The operation of the device is as follows: When the motor is dead, the piston is in its outer position, the cam actuated release sleeve is in its contracted or shortened position so that the throwout bearing does not impede the rearward travel of the release levers and the clutch is thus in a normally engaged position. Under these conditions the clutch is, to all purposes, a conventional one and may be used in a conventional manner for parking or turning the motor over by towing or pushing. However, when the operator starts the motor running, a vacuum is immediately created in the cylinder which draws the piston back. This in turn, through the cam action of the release sleeve, pushes the release levers forward to such a position as will accomplish clutch release at a normal idle speed of the engine.

Thus it will be seen that as long as a normal manifold depression is maintained, the vacuum cylinder will hold the release sleeve to a position which will insure automatic release at idle speeds. It is well known, however, that manifold depression is not constant, being maximum with a closed throttle position and dropping to nearly zero under full throttle conditions. We take advantage of this fact and obtain a very important operating characteristic by the use of this vacuum conversion system.

Picture, if you will, pulling a long hard grade in high gear. The throttle is wide open and the engine speed is gradually decreasing until it is approaching the normal idling speed. Without the vacuum conversion system, when these conditions are reached, the centrifugal clutch will begin to slip because its torque capacity is dependent entirely upon rotative speed. It will not permit the engine to stall, it is true, but may in the hands of an inexpert driver do considerable damage through excessive slippage.

With the vacuum conversion system this cannot happen, since the condition was obtained with a full open throttle

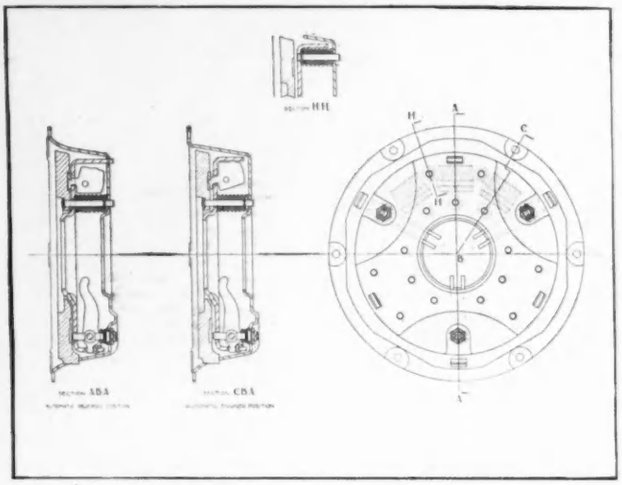


Fig. 6—A Borg & Beck Centrifugal Clutch

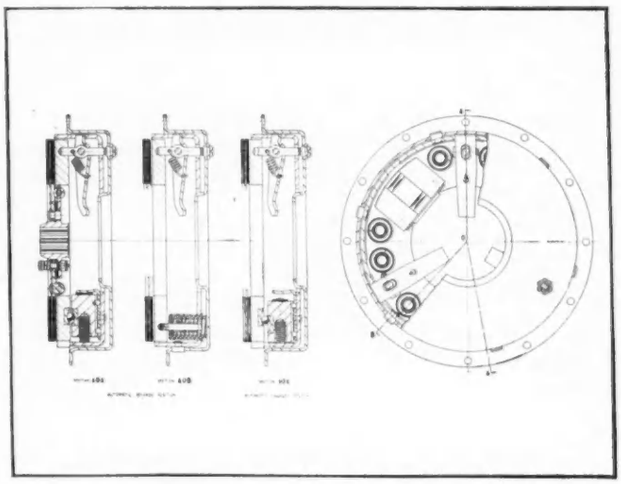


Fig. 7—Centrifugal Clutch Designed by Long

and therefore a very low manifold depression. A low manifold depression is not sufficient to maintain the vacuum cylinder piston at its "in" position against the resistance of the clutch pressure springs. Therefore at low manifold depressions the clutch automatically becomes conventional and will hold without slipping at as low a speed as is possible to run the engine. An easing up of the accelerator will again raise the manifold depression and the clutch returns to its automatic position.

The action of the vacuum conversion system may be summarized as follows:

First—It makes the clutch automatic under all normal driving conditions but renders it conventional under such conditions as would normally tend toward excessive slippage, thus taking the operation out of the control of the driver and making it respond automatically as extreme driving conditions arise.

Second—It makes the clutch conventional with the shutting off of the engine without extra operations and without need for knowledge on the part of the driver.

Free Wheeling

The fouth essential to the success of an automatic clutch of this type lies in its use in conjunction with a free wheeling element in the transmission line. True, this type may be used without free wheeling, but in this case it is necessary to declutch with each change of gears. The advantage of being able to wait at a traffic light without having to hold the clutch out is, of course, maintained, as well as the advantage of getting into gear from a stand without declutching.

The full benefits to be gained from this type of clutch, however, require the use of a free wheeling element. The action then becomes truly automatic. All functions of the clutch from a manouvering control in parking, to a quick get-away in traffic, an easy gear change at all reasonable speeds, preselection of gear change when approaching a stop, waiting at traffic lights—all these can be accomplished without use of the clutch pedal and without special technique on the part of the operator.

One of the most important functions of a centrifugal clutch, however, lies in the fact that its use practically standardizes drivers from the standpoint of clutch operation.

With a conventional clutch an engagement is a subconscious synchronizing of two functions—motor speed controlled by the right foot and clutch pedal position controlled by the left foot. Each driver through experience develops this technique in his own way, and in very many cases, his way is very hard on clutch facing life. Thus it is that one driver may obtain a facing life of 50,000 miles or more and another driver in an identical make of car will require new facings after 10,000 miles. This problem is one that is entirely out of the control of the clutch manufacturer except through educational campaigns of doubtful value.

Centrifugal Clutch Advantages

With a centrifugal clutch, however, the problem is very much simplified, since an engagement is the result of one function only—motor speed—and this under the control of the right foot only. No synchronizing of separate functions is necessary and the resulting engagements are the same regardless of whose foot is depressing the accelerator.

Another advantage of centrifugal engagement results from the absence of high velocity slippage. Such slippage is extremely detrimental, because of the amount of heat generated and results in rapid facing wear. High velocity slippage is impossible in a properly designed centrifugal clutch because the torque capacity is dependent on engine speed only, and the clutch becomes an automatic torque governor between engine torque and rolling resistance requirements of the vehicle.

It would scarcely be fair to leave this subject without pointing out some of the disadvantages or difficulties which are more or less inherent to this type of design. Probably one of the most difficult problems lies in the proper balancing of the clutch. A centrifugal clutch design necessarily requires a weight system of considerable mass to insure its torque capacity. These weights are mounted at a considerable distance from center. Then, too, they must move a certain distance radially in order to perform their functions of engagement or disengagement. These necessary conditions for operation make balancing a difficult matter.

It would seem that there is but one good answer to the problem. First, the weights themselves must be selected and qualified carefully to a very close limit of tolerance. Second, positive stops—both outer and inner—must be provided for limiting the movement of the weights and these stops must

be maintained to a close limit of runout about center. Third, the design should include an arrangement whereby the weights are restrained from moving independently of each other, so that they will expand or contract in unison. This is about all that can be done. However, the balance at the positive stop positions can be held closely providing proper care is taken in the fabrication of the parts. This will take care of balance at motor idle speed and at speeds from about 1000 r.p.m. and up. The more or less uncertain balance will occur within the speed range between motor idle and about 1000 r.p.m. Fortunately most vibration disturbances are nearly negligible at such low motor speeds.

It is quite evident, however, that clutches of centrifugal design must necessarily require closer tolerances in many details and better workmanship in order to function properly. This is another way of saying that for comparable capacities their cost will be in excess of those of conventional design.

We have attempted to give in detail most of the problems arising in the design of a centrifugal type of clutch and its installation. These problems have been discussed in a general way and with as little reference as possible to particular designs. For those of you who prefer a picture to visualize a construction, we will show a few typical designs.

Fig. 4 is a foreign design, known as the N. A. G. Protos, manufactured by the Nationale Automobile Gesellschaft of Berlin. In this design the retractor springs of the weight system overcome the regular clutch spring pressure at motor idle speed, thus holding the clutch out. An increase of motor speed causes centrifugal force to overcome the retractor spring load and thus gradually brings the regular springs into action for engagement purposes. At high speed, centrifugal force entirely overcomes the retractor spring load, so the entire pressure spring load is effective for torque capacity purposes, and this load is a measure of the maximum torque capacity of the clutch. No conversion control is shown and therefore, a dead motor cannot be turned over by pushing or towing the car, neither can the motor be used as a brake in parking.

Powerflo Clutch

Fig. 5 shows a Powerflo automatic clutch exhibited at the New York Show in 1931. A centrifugally operated pressure plate is mounted on the front side of the driven member and a manually operable pressure plate on the rear side of the driven member. Suitable springs hold the weights at their "in" position at motor idle speed to give automatic release at that speed. An increase of motor speed causes the weights to move outwardly which in turn forces the forward pressure plate into engagement with the driven disc, the reaction to the pressure being taken by the regular pressure springs which support the rear pressure plate.

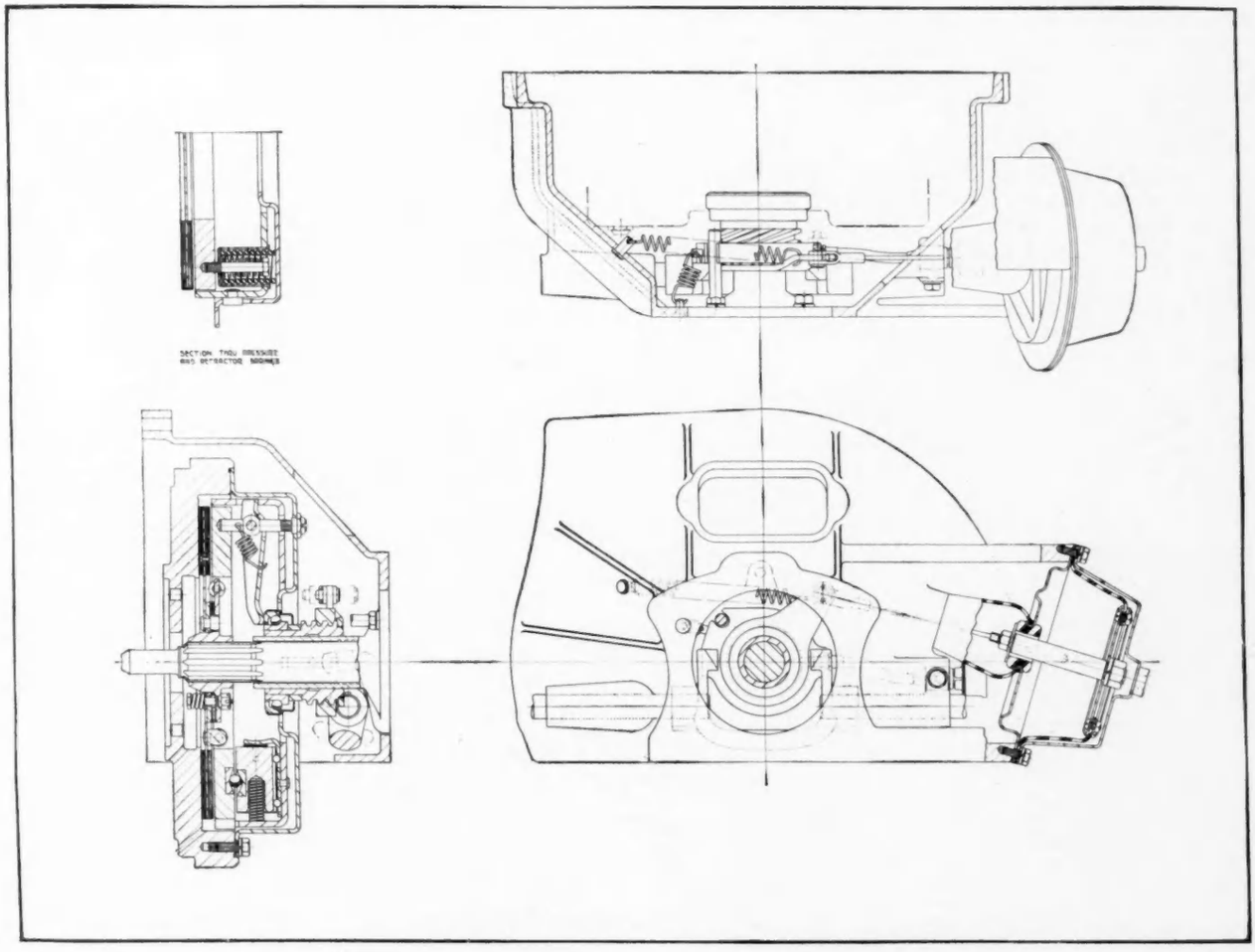


Fig. 8—Long Centrifugal Clutch in Installation with Vacuum Conversion System

With a further increase of speed the weights come to a positive stop provided on the coverplate at the same time compressing the pressure springs and forcing the rear pressure plate back to compensate for the advance of the front pressure plate. Manual release may be accomplished at any time by depressing the pedal in the regular way. This cut also illustrates the Powerflo conversion system previously described. The cam actuated sleeve is shown in its extended position where the throwout bearing impedes the rearward movement of the release levers and so holds the clutch in a position to insure automatic release at motor idle speed.

Fig. 6. shows a centrifugal clutch developed by the Borg & Beck Company of Chicago. Nine laminated sets of weights constitute the centrifugal system. These weights fulcrum on approximate knife edges against hardened inserts mounted in the pressure plate. Three double sets of release levers are provided for retracting purposes and the pressure and retractor springs are grouped around the centrifugal weights.

Fig. 7 represents a centrifugal clutch as developed by our company. It is the same general design as the one shown previously. The centrifugal weight mounting is rather interesting in that the entire weight moves radially in and out in a straight line movement. It is mounted on two spaced rollers running in a track on the rear side of the weight. Co-acting cone seats respectively in the front side of the weight and rear face of the pressure plate, with a ball loosely placed in the cone seats, furnishes the means of moving the pressure plate axially as the weights move radially in or out. Manual release is effected through the usual release lever system.

Fig. 8 shows the same type of clutch in a complete installation with the vacuum conversion system. This particular drawing illustrates a screw type of release sleeve which acts exactly as does the cam operated sleeve in lengthening or shortening the effective release sleeve length. The arrangement of the vacuum cylinder unit should be obvious from the illustration.

It would appear from the interest now exhibited in centrifugal clutches that this type may be developed quite rapidly in this country within the next few years.

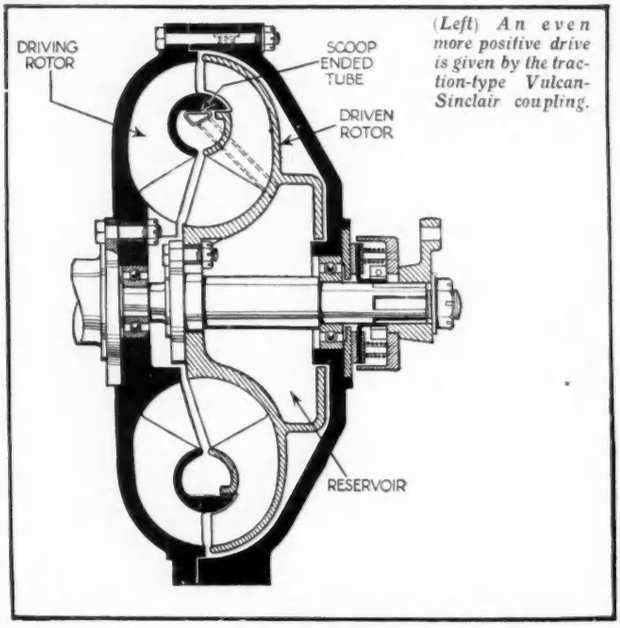
Fluid Couplings

The hydraulic coupling, more commonly known under the name of fluid flywheel, has been known in a general way to the industry for some time. It originated in Germany and was developed primarily as a drive between turbines and propeller shafts for marine installations.

The first important development of this type of coupling in the automotive field occurred when the Daimler Company of England put it into production in connection with the Wilson self-changing epicyclic gear box. Certain important changes and improvements have been recently made, making the adaption of this type of coupling practicable in connection with a standard type of gear box. These improvements may well become a part of our A-B-C's as applied to this particular art.

The most important characteristic of this coupling which retarded its adaption to automotive practice is the fact that at idling speed of the motor there is a residual drag between the driver and runner of the device tending to cause a pronounced gear clash if attempting to enter low gear or a pronounced gear tooth drag is attempting to shift to neutral.

Many attempts have been made to overcome this difficulty. The latest and probably the most successful effort results in what is known as the "Vulcan Sinclair Traction Coupling."



(Left) An even more positive drive is given by the traction-type Vulcan-Sinclair coupling.

Fig. 9—The Vulcan Sinclair Traction-Type Coupling

In this mechanism the runner member incorporates a closed reservoir chamber adjacent to its center, and from this chamber extends a plurality of tubes with scoop shaped ends, the scooped ends extending into the central vortex chamber of the driving member.

Under starting conditions the internal reservoir being a part of the runner member is stationary and is filled with liquid picked up by the scoop tubes from the outer or working circuit.

As the runner member picks up speed upon acceleration of the vehicle the scoop action of the tubes diminishes because of the counter-balancing action of centrifugal force of the liquid in the central reservoir. Further increase in speed will completely stop the scoop action of the tubes and the liquid in the central reservoir will be returned to the working circuit through centrifugal force. This device tends to reduce residual drag at idling speeds by by-passing a large amount of the liquid from the working circuit to the central reservoir at such speeds. The mechanism is simple in construction and depends only upon inertia and centrifugal force for its proper action. A device of this character is shown in Fig. 9.

It is admitted by the manufacturers of the coupling that the improved emptying mechanism is not entirely perfect in action and that there still remains some residual drag at idle speeds. To overcome this they have devised what they term a rocking clutch brake. This is shown in Fig. 10.

It consists of an internal brake drum carried on the clutch shaft, and a rocking member, mounted on the front of the gear box, which carries two expanding brake shoes operating inside the brake drum. The first part of the clutch pedal movement causes the shoes to expand and engage the brake drum to bring it to rest. A further movement causes the rocking member and brake drum to rotate through a small angle contrary to the direction of rotation of the engine, thus relieving any torque load on the gear teeth of the transmission if they be engaged.

With these two devices it is claimed that the use of the

hydraulic coupling is practical in connection with a standard type of gear box and in conjunction with a free wheeling unit in the transmission line.

A combination of this sort is shown in Fig. 11, which should be clear from the explanation above.

It should be noted that the pedal operated by the left foot and commonly called the clutch pedal in this case is called the gear change pedal. It must be depressed in the usual manner to accomplish a gear change although under a very light load, since there can be no declutching of this type of device and only auxiliary functions are performed by the depressing of the pedal.

With the arrangement shown, however, it can scarcely be termed automatic except in the sense that the engagement is automatic after a gear change is made and the accelerator is again depressed.

It is also interesting to note that this type does not include a conversion system and that a dead motor cannot be started by pushing or towing the car, neither can the motor be utilized as a parking brake.

Of the two types of automatic clutches—centrifugal and hydraulic—it would appear that the former is the best suited for American practice at the present time. Its application can be made with fewer departures from present practice; it can be made to operate more truly as an automatic clutch and still retain the auxiliary functions which we now deem essential. The hydraulic type, however, is a very interesting one and with further development and simplifications may become a serious competitor in the automatic clutch field in the future.

Clutch Control

By "clutch control" is meant the control of a conventional type of clutch through an external agency such as the vacuum control, as in distinction from the two previous types discussed in which the automatic action of engagement or disengagement is inherent in the design of the clutch proper.

The vacuum controlled clutch has been the most widely used of any of the socalled automatic clutches and its general principles are undoubtedly familiar to you all.

It consists primarily of a vacuum control cylinder, whose piston is connected to the conventional clutch pedal linkage. In the tubular connection between the cylinder and intake manifold is a control valve whose piston is mechanically linked to the accelerator pedal in such a way that when the accelerator is in the closed throttle position the piston in the control valve assembly uncovers a port, allowing manifold

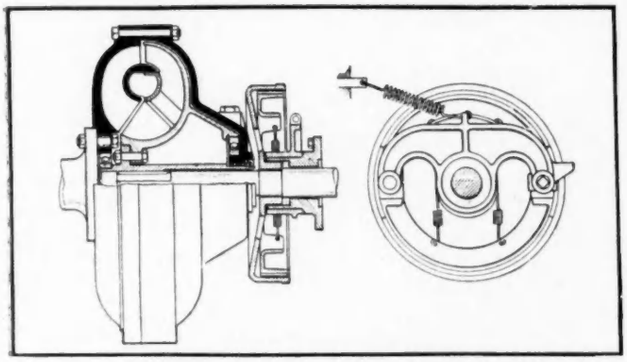


Fig. 10—Rocking Clutch Brake, Designed to Overcome Residual Drag at Idle Speeds in Traction Coupling Illustrated in Fig. 9

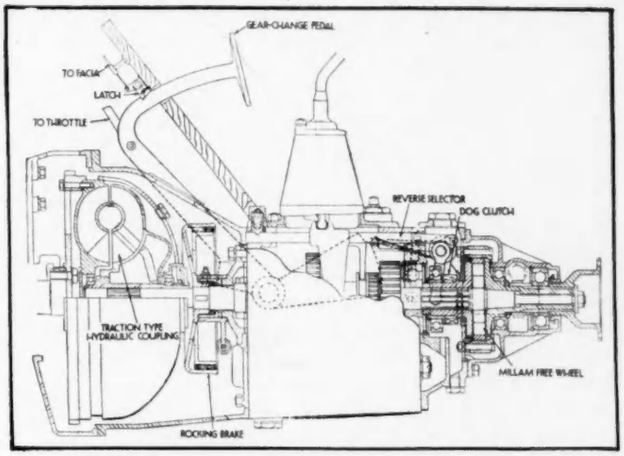


Fig. 11—Hydraulic Coupling Installed with Standard Gearbox and in Conjunction with Transmission-Line Free-Wheeling Unit

depression to be effective on the suction side of the control cylinder. Atmospheric pressure on the opposing side of the control piston forces it to its "in" position, thereby releasing the clutch.

When it is desired to start the car, the accelerator is depressed in the usual manner. This causes the piston valve in the control valve assembly first to close the port opening to the intake manifold and then to open a bleeder port to atmosphere, thereby quickly relieving the negative pressure on the suction side of the control piston. As the pressure becomes balanced on both sides of the control piston, the clutch pressure springs cause the piston to move outward at a rapid rate, the air on the atmospheric side of the control piston escaping through a milled slot in the piston rod where the piston rod passes through the glands in the cylinder head.

The control piston as it travels outward finally closes this relief port as the end of the milled slot is covered by the packing gland. This causes the piston to be checked abruptly in its outward movement, corresponding to the point where the clutch pressure plate is about to engage the friction facings of the driven member. This is known as the checking point or cushioning point and is the point at which actual engagement begins. The control piston must be caused to move more slowly from this point in order to accomplish smooth engagement. To effect this action, a bleeder line is run from the cylinder head to the side of the control valve assembly where a longitudinal port in the control valve piston permits of a bleeding action of the remaining trapped air on the atmospheric side of the control cylinder piston to assure a gradual engaging action.

In this way, the vacuum control is made to simulate the action of the foot in either clutching or declutching a conventional type clutch, and all through the action of the accelerator pedal.

If the type of a clutch engagement could be standardized so that in driving only one standard engagement were used, the problems then of a mechanical foot would be greatly simplified. However, in actual practice, the types of engagement are many, ranging from a maneuvering control while parking to a quick get-away at a traffic light, with the accelerator pressed to the toe board. So the problem of smooth engagement at these extremes as well as the mean between them becomes a difficult one. The same problem is again

magnified in difficulty by the fact that a gear change box is a necessary part of the anatomy of an automobile, and that the proper slippage time to assure a smooth start in low gear is altogether too long a slippage time when shifting from second to high with the car already in motion. Or conversely, a slippage interval assuring a smooth start in second gear will cause a crabby action of the clutch in low gear.

These are some of the engagement problems attached to this type of device, and it is a tribute to the manufacturers' ingenuity that they have been solved as well as they have.

The Bendex Corporation, a very large producer of this type of device, is showing some very clever improvements devised to overcome some of the difficulties of engagement just enumerated which should be interesting to note.

Fig. 12 illustrates the general installation of one of their new products in a popular car. The general arrangement of the parts conforms to previous practice, the principal improvement being known as a pendulum valve or cushion control valve. This valve consists of a pivoted pendulum weight hanging in a substantially vertical plane and arranged to operate a sliding piston valve mounted in the housing of the device, the piston valve in turn resisting movement in one direction through flexing of an adjustable spring likewise mounted in the same housing. The pendulum weight by reason of its own inertia will actuate the piston valve upon forward acceleration of the car to vary a port opening in the valve housing. This type of valve is shown in section as well as in its assembled location on the control cylinder in Fig. 13. In assembly it is interposed in the bleeder line between the cylinder and the accelerator control valve.

In starting in low gear, as the clutch begins to engage through the bleeder action of the control valve piston, the car begins to accelerate. If the clutch engagement is too rapid, the acceleration of the car will cause the pendulum to swing backward partially or entirely, closing the bleeder line port in the pendulum valve housing. This action in turn further restricts the orifice in the bleeder line, thereby slowing up the engagement action.

The maximum possible acceleration in second or high gear is much less than that of first gear. By the same token, the movement of the pendulum valve in second or high gear starts is much less pronounced. In fact, by a properly worked out spring it is said that the pendulum valve action may be confined almost entirely to low gear starts where it is most needed.

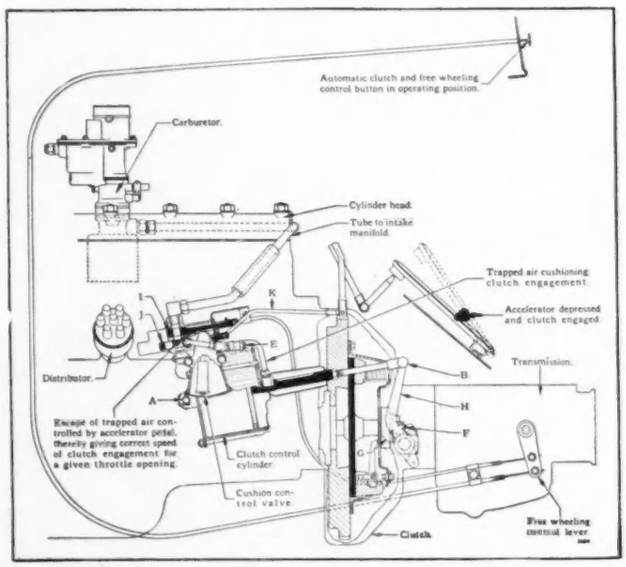

Automatic clutch and free wheeling control button in operating position.
Carburetor.
Cylinder head.
Tube to intake manifold.
Trapped air cushioning clutch engagement.
Accelerator depressed and clutch engaged.
Transmission.
Distributor.
Escape of trapped air controlled by accelerator pedal, thereby giving correct speed of clutch engagement for a given throttle opening.
Clutch control cylinder.
Cushion control valve.
Clutch.
Free wheeling manual lever.

Fig. 12—Bendix Automatic Clutch Installation

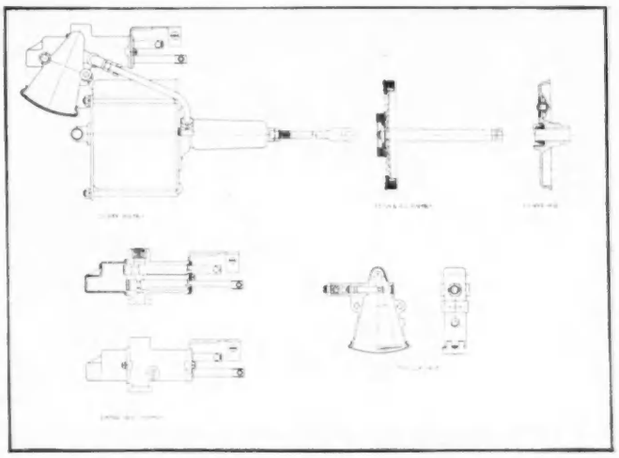


Fig. 13—Detail of New Cushion Control Valve Used in Bendix Automatic Clutch

The control valve is also shown in section in the lower left of Fig. 13. This assembly also has been improved in the port construction of the piston. The cross milled slot in the lower piston valve or accelerator control valve is for the purpose of very rapidly returning the negative pressure on the suction side of the main cylinder piston to atmospheric pressure so that in a quick start the piston will return to the cushioning point rapidly. The land between the groove in the accelerator control piston and the cross milled slot is just sufficiently wide to cover the port width in the housing, so that this dumping action of the air in the main cylinder is accomplished quickly. There is sufficient leakage around this land in a maneuvering start in parking, with the motor idling, to insure a gradual engagement during this operation.

The upper piston in the control valve assembly is a shut-off valve for the purpose of rendering the control mechanism inoperative at will. It is connected to a dash control button and also to the free wheeling control which is operated by the same control button.

The two upper right views are details of the piston and piston rod assembly and the cylinder head assembly. An improvement has been made in the piston construction by the introduction of a spring-pressed, oil-soaked felt ring mounted on the inside of the piston leather seal. The felt ring is under spring pressure on two sides and by being in direct contact with the leather causes the leather to absorb oil from the oil-soaked felt ring. This feature is designed to increase greatly the time interval between oilings. The milled port in the piston rod is shown and it will be noted that it extends entirely through the rod.

The section through the cylinder head shows the packing gland construction as well as the flapper check valve for quickly admitting air to the atmospheric side of the main piston upon disengagement of the clutch.

Fig. 14 is a more comprehensive view of the control cylinder assembly. In its installation in the car the cylinder is set at such an angle as will make the pendulum valve piston lie in a horizontal plane. The end elevations clearly show the

mounting of the pendulum valve and the piping arrangement to the cylinder and control valve housing.

The automatic vacuum clutch control has been used in production by car manufacturers both with and without a free wheeling unit in conjunction with it. There are arguments, of course, favorable and unfavorable to both hookups.

Inherently, the vacuum clutch control disengages the clutch each time the foot is raised from the accelerator and in that way introduces a free wheeling action. This is open to some criticism, however, in that the time element of the declutching action, at high car speeds or under conditions of low manifold depression, may be sufficiently long to cause a slight lunge as the car speed overruns that of the engine. The same may be true too in accelerating the motor to come out of the free wheeling condition at high car speeds.

Probably the most serious objection in operation to the omission of a free wheeling unit in the transmission line is that of gear shifting. Without such a unit, the polar moment of the clutch driven member is of as much importance to easy gear shifting as in a car equipped with a conventional clutch. This is particularly true in cold weather driving before the transmission oil has had an opportunity to warm up.

On the other hand, a vacuum control unit in conjunction with a conventional free wheeling unit in the transmission line makes gear shifting a very easy problem. At the time of making the gear change, assuming the car already in motion, the transmission is not in driving connection with either the engine at one end of the transmission or the propeller shaft at the other end. In other words, it is a free unit, at the moment, and the gears may be shifted easily at will.

Another of the serious difficulties in an installation of a vacuum control unit lies in maintaining the proper cushioning adjustment. This adjustment must check the rapid return of the control piston just as the clutch pressure plate begins to contact the friction facings. If it is checked too soon, the engine will run away from the clutch; if too late, a poor engagament will result. The adjustment is important to the successful operation of the device and is one which must be maintained. Naturally, normal wear of the friction facings will affect this adjustment and such wear must be compensated for at intervals in order to maintain the proper operation of the device. A vacuum clutch control made by the Hill Engineering Company is designed to check at the proper cushioning point by a pressure balancing arrangement as the pressure plate comes in light contact with the friction facings and therefore is independent of facing wear.

Such a principle if otherwise properly worked out in detail might go a long way toward overcoming this difficulty.

And so we have looked them over, the principal new developments which may become a part of our A-B-C's we must learn. Undoubtedly there are other developments in process. Some are still held a secret, others we know a little about, but are not privileged to discuss, and still others we would like to know a lot about, yet know very little.

Which will it be? Some of the now unknowns? Or possibly it will be one of our more familiar friends from the trio of vacuum control, fluid couplings, or centrifugal clutches that will give us our next important epoch in automotive clutches? Frankly, I do not know. I will leave it to you.

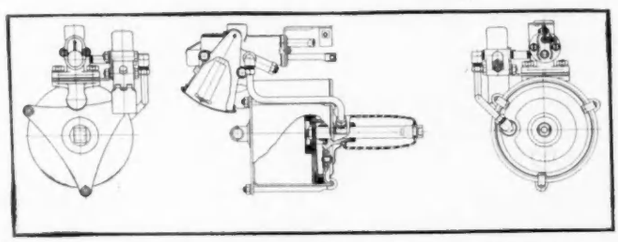


Fig. 14—A More Comprehensive View of the Control Cylinder Assembly Shown in Fig. 13

Engineers Serve Mankind Effectively

THIS is the first depression which engineers really have been blamed for. And we have felt it like the other classes of society. We have had to stand our share of the grief. But I really think that it is adding insult to injury when the scientist and those who apply science to the uses of mankind are blamed for the depression.

We have freed the world from the physical menace of famine. We have raised the general standards of living. We have supplied mankind with increased leisure. We have provided new means and opportunities for education, entertainment and amusement, and we have relieved man of much of the worst drudgery of labor. This in itself is a great achievement.

I don't have to ask you men whether it is all over. You know as to your own industries that the progress in your industry is not done.

Engineers' Contribution

We engineers can congratulate ourselves on the contributions that have been made to civilization. The problems of this era are not the problems of the past. If you will read the economic history of the past you will see that, up to a period of 150 years ago, the problems of the world were problems of want. The methods of production did not permit of producing enough to enable more than a very small number of the inhabitants of the world to live on any basis above a bare level of sustenance. Our problem today is entirely different, and should be a very much simpler one.

The problem that must be solved now is the problem of not being able to produce enough to keep the bulk of the people of the United States above the level of want. It is a problem of having the ability to produce it, of finding how to distribute it to the population. That, I think, is the major contribution to the world of the scientist and of those who have worked on the application of science, the engineer and others.

To quote from Macaulay, the English essayist, whose writings were published 103 years ago, and whose words are better than any that I can find for myself to express this idea:

"We cannot absolutely prove that those are in error who tell us that society has reached the turning point, that we have seen our best days. But so said all who came before us, and with just as much apparent reason."

It is my personal conviction, and I firmly believe, that the future holds in store for us engineers opportunities at least as great, if not greater, than any we have had in the past.—Bancroft Gherardi, vice-president, American Telephone & Telegraph Co., at 1933 Annual Dinner of S.A.E.

Antiknock Report Gets Discussion

Below is discussion of the report by Veal, Best, Campbell and Holaday which begins on the page directly opposite.

D. P. BARNARD[14]:—It has often been stated that a service engine could not be built which would perform on a representative cracked gasoline as predicated by the C.F.R. Research Method of test. Figs. 1 and 2 show the results obtained on two engines operated on the same series of fuels, designated as Engine No. 1. and Engine No. 2. While Fig. 1 shows that the cracked fuel of 68 octane number—C.F.R. Research Method—was depreciated about six octane numbers by tests made with this car, making it equivalent to a 62-octane number virgin-gasoline, the engine represented in Fig. 2 did not depreciate the cracked fuel and, in fact, showed an appreciating effect on this fuel. It should be noted that the engine which did not depreciate the cracked gasoline had an efficient combustion-chamber design and high volumetric efficiency; and that no excessive amount of heat was added to the intake charge by the use of exhaust gases, the heat being supplied by a hot-spot heated by the cooling water which was thermostatically controlled to maintain uniform temperature.

Data of this type, supported as it is by modification made in the C.F.R. research procedure to give correlation of our laboratory test engines with service tests, make a very strong appeal to continue the study of the problem suggested by these tests to determine engine-design factors which effect the depreciation of cracked gasolines.

Tests show that benzene actually loses in antiknock value about 20 to 25 octane numbers between the C.F.R. Research Method and the C.F.R. Motor Method of test, while several cracked gasolines lose as much as 10 octane numbers.

One can easily visualize the gain in performance of a car that could be obtained by designing an engine to operate on a fuel having an octane-number value 10 octane numbers higher than the present standard fuels, while it is not impractical to expect that careful design may not result in an engine giving results on cracked gasolines even more favorable than those obtained by the C.F.R. Research Method of test.

H. W. BEST[15]:—We know of five changes in operating conditions which are effective in bringing about correlation of the laboratory engine; namely, increased speed, increased mixture temperature, increased jacket temperature, throttling the intake and throttling the exhaust. All of these changes, it seems, increase the temperature of the charge at the time of ignition. Throttling does this because of the higher percentage of hot exhaust gases; increased speed, perhaps because of decreased volumetric efficiency, hotter exhaust gases and hotter cylinder walls; and increased jacket temperatures, because of hotter cylinder walls and intake ports and reduced volumetric efficiency. Thus it may be that all of the modifications in the C.F.R. research procedure which give results that correlate with service conditions are just different ways of producing the same condition; namely, higher charge temperatures. This condition is perhaps obtained in automobile engines not entirely because of high manifold temperatures and hot intake air but because of other factors such as back pressure and relatively low volumetric efficiency at certain speeds or hot spots. For instance, Car 2 rated certain fuels low at high speeds; 30 to 40 m.p.h. Might this not be due to low volumetric efficiency and high back pressure at these speeds, which would increase the charge temperature due to increased exhaust-gas dilution? The reference fuels are not sensitive to this condition and did not give the high-speed knock in this car which the other fuels did; therefore the low rating at these critical speeds.

[14]M.S.A.E.—Research engineer, Standard Oil Co. (Ind.), Whiting, Ind.
[15]M.S.A.E.—Instructor in mechanical engineering, School of Engineering, Yale University, New Haven, Conn.

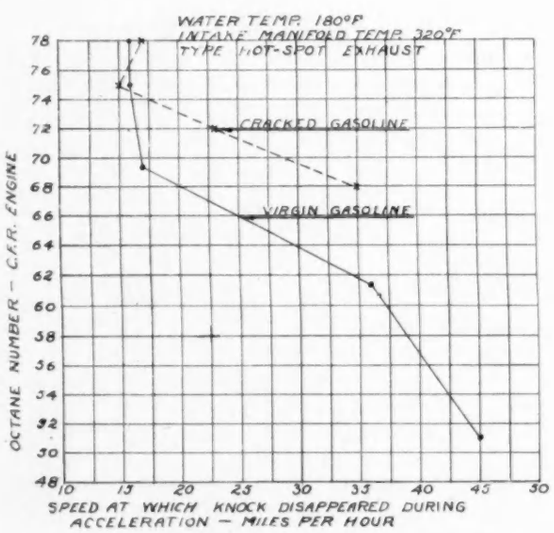


Fig. 1—Results of Tests on Engine No. 1 Equipped with a Combustion Chamber Having a Flat Cylindrical Valve in the Head

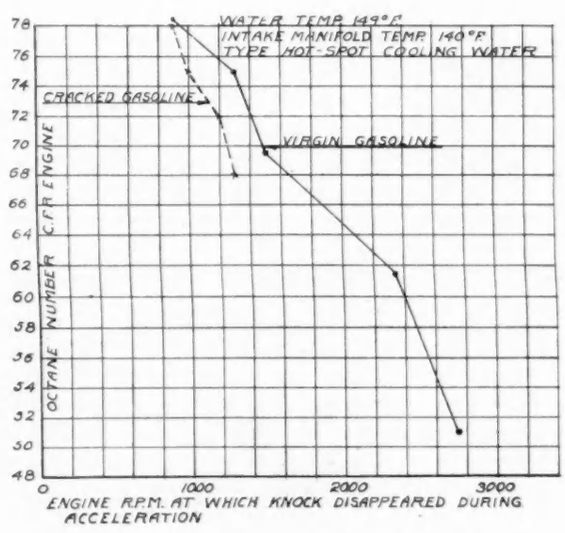


Fig. 2—Results of Tests on Engine No. 2 Equipped with a Combustion Chamber Having a Pent Roof and an Inclined Valve in the Head

Antiknock Research Coordinates Laboratory and Road Tests

By C. B. Veal[1], H. W. Best[2], J. M. Campbell[3], and W. M. Holaday[4]

ALTHOUGH the C.F.R. Engine-Test Method of knock evaluation, now designated as the Research Method, is accurate and reproducible to a remarkable degree, investigation developed that it was not adequately simulating service conditions as judged by the most critical technician or the less critical lay user.

To bring the laboratory method in line with road evaluation of a fuel, a definite technique of road test was evolved that, while not to be considered in commercially determining octane numbers, was regarded by the Committee as sufficiently accurate and reproducible to serve as the first step in the development of a satisfactory laboratory method.

With a satisfactory road-test method available, the next step was to test a representative group of fuels and then develop a laboratory method which closely approximates the road results. The method finally adopted—a logical outgrowth of the original procedure, evolved by modifications consistent with the development as originally contemplated—meets this requirement with an extremely close approximation of the road observations.

THE FIELD of this paper is the course of the detonation-testing project of the Cooperative Fuel Research Committee since its last report to the Society on this topic at the 1931 Annual Meeting. The first part of this period will be covered, so that this Society may have before it a complete story of this important section of its Research Activity; but only in summary form, and references made to earlier detailed reports published elsewhere. A fuller treatment will be given to the more recent events and specifically to the possible application of the results in automotive-engine development.

Detonation Symposium

The Detonation Symposium presented at the Annual Meeting two years ago included a description of the Cooperative Fuel-Research-Committee engine for laboratory knock-testing and reports contributed by committee members and other cooperating laboratories on the effects of various engine and atmospheric variables on the observed knock intensities of fuels. Two phases of rating methods were also dealt with.

The development of the Cooperative-Fuel-Research-Committee engine was one important accomplishment in the first section of a triple program before the Subcommittee on Methods of Measuring Detonation, which was particularly charged with the knock-testing project of the joint automotive and petroleum fuel research. Within the first years of its existence, in January, 1929, the Subcommittee recognized the ultimate importance of road tests in determining knock ratings of motor gasolines. The user of the fuel was acknowledged as the final arbiter, and the degree of knock experienced by him on the road, as the commercially important criterion, whether or not it be a true scientific rating. However, the development of a tentative laboratory test seemed the first logical step. Such a laboratory test would give results which would serve as a basis of comparison with road ratings, and would serve as a foundation from which might be evolved a laboratory test yielding ratings truly representative of the results found in service.

Guided by this reasoning, the Subcommittee envisioned as its triple function: (*a*) to develop equipment and a simple practical reproducible laboratory method for knock determination; (*b*) to perfect a significant method of conducting road tests; and (*c*) to effect such modification of the laboratory method as might be found necessary to produce ratings in correlation with results obtained by the road-test method. This program applying to motor gasolines has been substantially completed.

During the progress of this work, and more particularly since its conclusion, there has been an insistent demand from both the aeronautic and the petroleum industries for the Committee to undertake a program directed toward obtain-

[This paper was presented at the 1933 Annual Meeting of the Society and is a Report of the Detonation Subcommittee of the Cooperative Fuel Research Steering Committee on the Correlation of C.F.R. Laboratory Knock Ratings with the Behavior of Motor Fuels in Service.]

[1]M.S.A.E.—Research manager, Society of Automotive Engineers, Inc., New York, N. Y.; secretary, Cooperative Fuel Research Committee.

[2]M.S.A.E.—Instructor in mechanical engineering, School of Engineering, Yale University, New Haven, Conn.

[3]Chemical engineer, General Motors Research Laboratories, Detroit.

[4]M.S.A.E.—Research engineer, Standard Oil Co. (Ind.), Whiting, Ind.

ing comparable methods which will do for aviation gasolines what has been accomplished with motor gasolines.

A conference for considering ways and means and for developing such a program was held with the approval of the Committee on Jan. 12, 1933. This conference, made up of representatives of the petroleum and aeronautic industries, formulated a general plan for the cooperative solution of the problem of measuring the antiknock quality of aviation gasoline, patterned after the program of the Road Test Correlating Subcommittee. Progress has already been made toward the accumulation and analysis of all data that can be made available to the Committee relative to the results of tests and the methods of test on multi-cylinder aircraft-engines; together with data relative to any laboratory methods that have been found to give reasonable correlation with performance in multi-cylinder engines, which it is expected will form the basis for the detailed development of a cooperative experimental program.

Laboratory Test Method Formulated

In the initial designing of the engine, the Subcommittee completed one item necessary for a laboratory test, the two others being a method of procedure and a reference scale. The Subcommittee further supplied these two requisites by working out the Octane-Number Scale[5], supplemented by a system of secondary reference fuels and drawing up a tentative recommended practice for making knock tests[6].

To determine the adequacy of the apparatus and procedure in obtaining accurate and reproducible results, the Subcommittee carried out with them a series of cooperative tests on eight fuels. The favorable results of these tests, completed in the summer of 1931, formed the basis on which the Cooperative Fuel Research Committee, at its regular meeting on Sept. 14, 1931, approved the knock-testing equipment as then developed for general use in the automotive and petroleum industries. The octane-number scale and the tentative procedure had previously been accepted.

A detailed report on this first section of the Subcommittee's program was made made by its Chairman, T. A. Boyd, to the American Petroleum Institute[7] at its Twelfth Annual Meeting, November, 1931. Included in this report are full descriptions of the C.F.R. knock-testing apparatus and procedure.

Cooperation of Foreign Groups

The cooperation of the Detonation Subcommittee with organizations from other countries which are interested in knock-testing was initiated through contacts early in 1930 with the British group now known as Standardization Committee No. 9 of the Institution of Petroleum Technologists. Members of this British committee attended and contributed to the Detonation Symposium at the 1931 Annual Meeting of the Society, and since that time the proceedings of our group and theirs have been regularly interchanged.

Also as a result of contacts established with Fritz Frank by Dr. H. C. Dickinson during attendance at the World Power Congress held in Berlin during the summer of 1930, the Subcommittee began an exchange of information and proceedings with Subcommittee 48 B-1 of the German Association for Testing Materials, on engine testing

During last summer, H. L. Horning arranged to combine with a business trip through Europe a series of contacts as the official representative of the Cooperative Fuel Research Committee. Immediately upon his arrival in London, Mr. Horning met the British Committee and, with its assistance, completed arrangements for personal contacts in France and Germany with a number of men prominent in engine and fuel-research work. During his stay in France a meeting was called of the Committee of Refiners and, subsequently, arrangements were made for an exchange of proceedings with this body. In Germany, Mr. Horning was a guest at

[5]See S.A.E. Handbook, p. 607.

[6]See S.A.E. Journal, August, 1931, p. 164.

[7]See *Proceedings of the American Petroleum Institute*, Section III, p. 46, (1931).

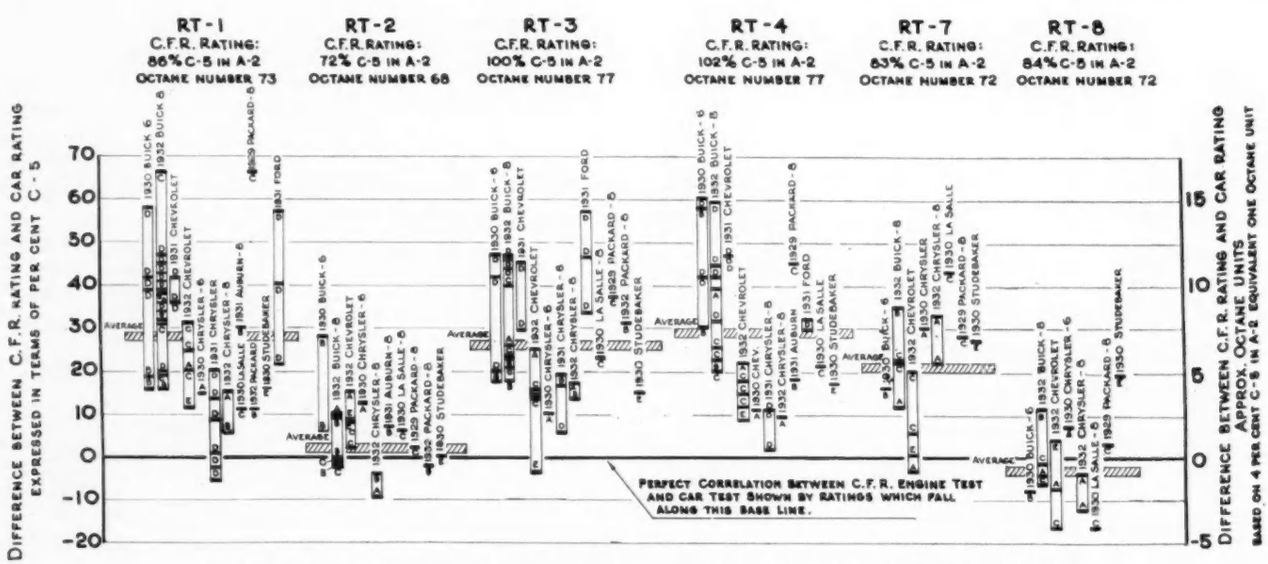

RT-1
C.F.R. RATING:
86% C-5 IN A-2
OCTANE NUMBER 73
RT-2
C.F.R. RATING:
72% C-5 IN A-2
OCTANE NUMBER 68
RT-3
C.F.R. RATING:
100% C-5 IN A-2
OCTANE NUMBER 77
RT-4
C.F.R. RATING:
102% C-5 IN A-2
OCTANE NUMBER 77
RT-7
C.F.R. RATING:
83% C-5 IN A-2
OCTANE NUMBER 72
RT-8
C.F.R. RATING:
84% C-5 IN A-2
OCTANE NUMBER 72
DIFFERENCE BETWEEN C.F.R. RATING AND CAR RATING EXPRESSED IN TERMS OF PER CENT C-5
DIFFERENCE BETWEEN C.F.R. RATING AND CAR RATING APPROX. OCTANE UNITS
BASED ON 4 PER CENT C-5 IN A-2 EQUIVALENT ONE OCTANE UNIT
AVERAGE
PERFECT CORRELATION BETWEEN C.F.R. ENGINE TEST AND CAR TEST SHOWN BY RATINGS WHICH FALL ALONG THIS BASE LINE.

Fig. 1—Relation Between C.F.R. Knock Rating and Car Rating for Six Different Fuels

Six different representative gasolines designated as *RT*-1, *RT*-2, *RT*-3, *RT*-4, *RT*-7 and *RT*-8 were compared with blends of two standard reference fuels designated as *C*-5 and *A*-2 in both the C.F.R. engine operated in accordance with the present standard procedure of knock testing and in the automobiles shown.

The vertical bars indicate the range in ratings that was observed for each make of car and the heavy horizontal dashes indicate each observation. The data obtained by each of the five cooperating laboratories are shown by the letters A, B, C, D and E, recorded beside each observation.

a specially called meeting of Subcommittee 48 B-1, already mentioned.

As a result of all these contacts, the Detonation Subcommittee has now established official relations with the groups in England, France and Germany, authorized by the interests in these countries to deal with the subject of knock-testing. It is hoped that such contacts as these between the Detonation Subcommittee and the corresponding groups in England, France and Germany, will lead to a mutual understanding of the problems with which we are dealing and to the eventual establishment of international standards of knock-testing.

Preliminary Road-Test Development

Having carried out the first part of its program, the Subcommittee turned its attention to the remaining two sections. As a necessary preliminary to formulating its own course of activity, it first studied the results of such separate oil laboratories as had made comparison of laboratory knock ratings with the behavior of fuels in service. Meeting in January, 1932, after having studied these reports, the Subcommittee divided the problem before it into two sections. It appointed a special Road Test Correlating Subcommittee on Road Test Procedure, with A. L. Beall as Chairman, and assigned as its task the carrying out of a series of cooperative road tests the results of which were to be compared with the conventional C.F.R. ratings. Second, it arranged for the carrying out by its members of laboratory tests to determine the effect on knock ratings of certain variations in the C.F.R. laboratory equipment and procedure.

The special Subcommittee on Road Test Procedure first determined road ratings with approximately thirteen cars on six selected fuels. The ratings were made by comparing the fuel to be tested with blends of reference fuels "*A*-2" and "*C*-5" of the Standard Oil Development Co., the speed at which knock died out during acceleration or became audible during deceleration being used as a criterion. For instance, if, with a mixture of 60 per cent *C*-5 in 40 per cent *A*-2, knocking stopped at 20 m.p.h., with a mixture of 40 per cent *C*-5 in 60 per cent *A*-2 at 30 m.p.h. and with the fuel under test at 25 m.p.h., then the rating of the fuel by interpolation was given as 50 per cent *C*-5 in 50 per cent *A*-2.

The results of this work as reported at a meeting of the Subcommittee on April 6, and by Mr. Boyd to the American Petroleum Institute at its Second Mid-Year Meeting, June 3, 1932, are shown graphically[8] in Fig. 1. These data show that the road ratings are, on the whole, decidedly lower than those obtained in the laboratory. However, there was such a wide range in ratings obtained on the road for most of the fuels that there was considerable question as to what the road rating should be.

Road-Test Procedure Recommended

It was therefore recommended that further work should be carried on by an enlarged committee to determine a more significant method of conducting road tests; namely:

(1) That road evaluations of fuels should be made in the speed range of 15 to 20 m.p.h. and shall be based on knock intensity.

(2) That the fuel under test shall be bracketed between blends of reference fuels such as *C*-5 and *A*-2.

These recommendations were an outgrowth of a conviction on the part of those engaged in the project that road-test data presented up to that time were based on knocking so faint as to be perceptible only to a trained expert and, therefore, were not rightly applicable to general conditions, as indicated by the subcommittee's primary precept that, essentially, a road test can be useful only insofar as it accurately reflects average consumer reaction to the characteristics of a fuel. Judged by this criterion of adequacy, the method based on incipient knock, or dying-out point of knock, appeared of doubtful value in determining the non-expert consumer's reaction. Further, experimentation with a method based on knock intensity showed that it had much to recommend it.

The specific recommendation of car speed was based on the belief at that time that the maximum intensity of knock rarely occurred above the road speeds indicated; that is, 15 to 20 m.p.h.

Tests Reported

With the acceptance of these recommendations the original special Subcommittee on Road-Test Procedure was discharged and replaced—Mr. Beall being retained as Chairman—by a larger and more representative group made up of volunteers pledged to carry on the work to a successful issue. This committee, known thereafter as the Road Test Correlating Subcommittee, as finally constituted, included in its membership representatives of 14 automotive and petroleum laboratories.

At the next meeting of the enlarged Subcommittee, experience in further testing was reported by its individual members. This showed that several 1932-model cars registered their maximum knock on the road at speeds in excess of 20 m.p.h. In view of this experience and a general agreement that further progress could be made rapidly only by intensive cooperative effort at some central point, it was arranged that an operating group, composed of one accredited representative of each member of the Road Test Correlating Subcommittee, with full authority to act, meet to conduct tests on typical present-day gasolines in representative cars. Upon the basis of this experience and analysis of the data obtained, the group was to reach agreement as to the most practical road-test procedure.

The Road Test Correlating Subcommittee met in Uniontown on Aug. 3, 1932, to start its tests on the Uniontown Hill. The accredited representatives and experienced operators from the various laboratories engaged in this work were:

H. W. Best, Yale University
F. C Burk, Vacuum Oil Co.
J. M. Campbell, General Motors Corp.
A. L. Clayden, Sun Oil Co. (N. Y.)
E. Dunning, Shell Petroleum Corp.
W. M. Holaday, Standard Oil Co. (Ind.)
G. A. Hope, Standard Oil Co (N. Y.)
C. A. Kass, Standard Oil Development Co.
A. W. Pope, Waukesha Motor Co.
J. R. Sabina, The Atlantic Refining Co.
C. B. Veal, Society of Automotive Engineers, Inc.; Secretary, Cooperative Fuel Research Committee
L. B. Voshall, the Texas Co.
Cleveland Walcutt, Ethyl Gasoline Corp.
Gilbert Way, Chrysler Motor Corp.
N. R. White, U. S. Bureau of Standards

[8] See *Proceedings of the American Petroleum Institute*, Division of Refining, p. 98, (1932).

Table 1—Cars in Which Fuels Were Rated

Name	Year and Model	No. of Cylinders	Compression Ratio
Buick	1932-67	8	Standard
Buick	1931-90	8	4.9:1
Chevrolet	1932	6	Standard
Chevrolet	1932	6	5.5:1
Chrysler	1932	8	Standard
Chrysler	1931	8	6.5:1
Dodge	1932	6	Standard
Dodge	1932	6	Optional high compression
Ford	A-1931	4	Standard
Ford	V-8-1932	8	Standard
Hudson	1932	8	Standard
Hudson	1932	8	7.0:1
Nash	10-80	8	Standard
Oldsmobile	1932	8	Standard
Plymouth	1932	4	Optional high compression
Studebaker	President-1932	8	Standard
Studebaker	President-1930	8	6.5:1

Others present who assisted materially in the formulation and conduct of the tests were:

A. L. Beall, Chairman; Vacuum Oil Co.
H. F. Huf, Vice-Chairman, The Atlantic Refining Co.
W. Anderson, Chrysler Motor Corp.
J. G. Cook, The Texas Co.
B. W Dickinson, U. S. Bureau of Standards
H. L. Horning, Waukesha Motor Co.
S. P. Marley, Vacuum Oil Co.
L. E. Rinker, Shell Petroleum Corp.

As listed in Table 1, 15 representative cars were used. These test cars were supplied by the following organizations:

The Atlantic Refining Co.
Chrysler Motor Corp.
Ethyl Gasoline Corp.
General Motors Corp.
Shell Petroleum Corp.
Standard Oil Co. (Ind.)
Standard Oil Co. (N. Y.)
Standard Oil Development Co.
The Texas Co.
The Vacuum Oil Co.

In these tests, 15 fuels were used, 11 of them being selected as representative of the entire range of commercial gasolines. Those making up the *"UT"* series were fuels sold commercially under the names of: Gulf, Tydol, Sunoco, Texaco, Atlantic White Flash, U. S. Motor, Amoco, Atlantic Ethyl, Penreco Ethyl, and a cracked and a straight-run California gasoline. These fuels were dyed uniformly red and labeled by a system of letters and numbers, the key to which, known only to the secretary of the committee, has since been destroyed.

The other four were special fuels, including a liquid-phase cracked naphtha, a vapor-phase cracked naphtha, a blend of 65 per cent of the liquid-phase cracked naphtha and 35 per cent of reference fuel *A*-2 and a blend of 50 per cent of the vapor-phase cracked naphtha and 50 per cent of reference fuel *A*-2. These special fuels were known as the *"RT"* series.

The U. S. Bureau of Standards furnished the inspection data on the test fuels given in Table 2.

The quantity of reference fuels *C*-6 and *A*-2 required for the tests, together with their inspection data as shown in Table 2, were contributed by the Standard Oil Development Co.

The tests were conducted on the Uniontown Hill, located near Uniontown, Pa., on the National Pike. The road has a concrete surface and the distance up this hill is approximately 2.5 miles. Beginning at the bottom the grades up this hill are approximately as follows: 1000 ft., 8.9 per cent grade; 1000 ft., 4 per cent grade; 700 ft., 0.50 per cent grade; and 10,600 ft., 8.9 per cent grade.

Development of a Road-Test Procedure

The problem before the Road-Test Correlating Subcommittee at Uniontown was to develop a suitable method for rating fuels in cars and then to rate by this method the 15 fuels selected. The operating group in the very beginning laid down the rule that no operator was to be denied the privilege of conducting tests in any way he desired, and urged all observers to use all methods which in their opinion gave promise of contributing to the solution of the major problem; the idea being to bring into comparison the widest diversity of methods.

To make the tests under as representative conditions as possible, they were conducted during wide-open-throttle operation in standard cars in which the spark timings and carbureter settings were adjusted as recommended by the car manufacturers. Exceptions to this ruling were made in the cases of Car 13, in which the manifolding was not of standard design, and Cars 14 and 15, which were equipped with extra-high-compression heads. The observers were urged not to confine themselves to a method involving ratings made at a single knock intensity, but rather to obtain ratings at various knock intensities and over the entire range of speeds at which knocking occurred. No definite specification was laid down as to whether tests should be made during slow acceleration, slow deceleration or at constant speed, the use of brakes being permitted to control the speed if necessary. Subsequent experience on certain cars showed that such a specification was not necessary because variations in this part of the procedure produced no significant variation in knock ratings.

In view of the foregoing fact this flexibility in operating technique was retained, thus enabling different observers to adopt a method best suited to the fuel to be rated. For instance in some cases, to obtain data in the desired speed range, the portion of the hill on which the test readings were to be made had to be approached at high speed; whereas, in other cases, a low approach speed, such as 15 m.p.h., and then acceleration to the higher speeds was more desirable. In any case the car was driven for some distance—usually about ½ mile up the approach to the test portion of the hill before the tests were actually begun—to obtain equilibrium conditions. Fuels were usually changed during the trip downhill, and in the preparatory run up-hill either the fuel to be rated or one of the reference-fuel mixtures were used.

The general procedure was to match the fuel under test

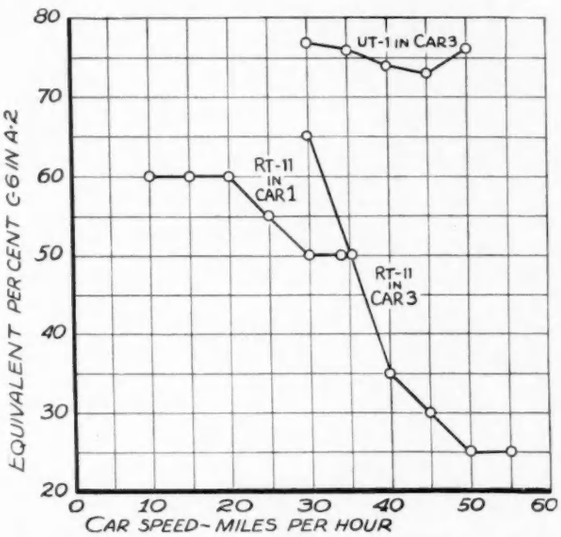


Fig. 2—Ratings Obtained on One Fuel; That Is, *RT*-11, in Cars 1 and 3. The Ratings on Fuel *UT*-1 Are Shown Also

with a mixture of reference fuels *C*-6 and *A*-2, basing the comparison upon knock intensity as judged by ear. The matching was carried out so that the test fuel fell between a reference-fuel mixture of higher antiknock value and a reference-fuel mixture of lower antiknock value, the mixtures of reference fuels differing in composition by not more than 20 per cent of *C*-6 in *A*-2, or the equivalent of about five octane numbers. Ratings were made at intervals of 5 m.p.h., usually beginning at speeds between 10 and 15 m.p.h. and extending up to the speed at which knocking disappeared.

With few exceptions, each rating was made by at least two groups of observers working independently, each group containing three men. Additional groups were assigned to make further ratings on fuel if the first two groups did not reach substantial agreement.

The ratings made by the several groups on a given fuel at the same speed, using a given car, showed a greater degree of reproducibility than might well have been expected; and, accordingly, served as reassuring evidence of the correctness of the general form of attack. However, different cars rated the same fuel differently, and the same car in some cases rated one fuel differently at different speeds.

Fig. 2 shows the ratings obtained on one fuel, *RT*-11, in

Table 2—Inspection Data

Furnished by the U. S. Bureau of Standards

	Test Fuels[a]															Reference Fuels	
Sample No.	*W*-1	*W*-2	*W*-3	*W*-4	*W*-5	*W*-6	*W*-7	*W*-8	*W*-9	*W*-10	*W*-11	*W*-12	*W*-13	*W*-14	*W*-15	*A*-2	*C*-6
Gravity, deg. A. P. I.	58.9	60.5	55.9	60.2	54.9	57.4	50.6	59.7	56.9	58.4	55.2	60.2	57.4	54.2	56.9	60.3	67.3
A. S. T. M. Distillation[b]:	Temperature, Deg. Fahr.																
First Drop	102	95	113	117	108	106	106	102	102	100	95	118	106	104	111	115	122
Per-Cent Point:																	
5	136	124	160	144	140	142	138	129	136	129	127	151	149	131	149	164	142
10	156	136	180	153	158	158	153	145	153	145	144	169	165	149	167	181	149
20	187	162	212	169	178	178	178	178	180	178	176	199	194	183	192	203	159
30	210	187	230	183	216	214	196	205	205	207	207	225	217	217	216	221	168
40	230	210	244	194	234	234	214	230	228	230	235	246	235	248	235	238	176
50	246	232	259	207	252	253	235	252	252	252	264	264	253	277	257	253	184
60	262	253	273	221	295	273	270	273	271	273	289	284	271	307	270	270	194
70	280	271	288	239	322	293	306	295	295	298	320	309	291	338	306	288	205
80	306	304	309	268	352	322	338	322	320	325	351	334	316	365	331	311	221
90	334	358	329	302	383	358	370	351	352	358	381	367	347	396	...	341	248
95	361	392	345	329	403	387	396	383	379	385	401	392	379	415	387	366	282
End Point	388	428	365	361	415	410	408	394	405	405	408	415	405	424	403	389	316
Recovery, per cent	97.9	98.2	98.0	97.5	97.8	98.0	97.8	97.0	97.7	97.8	97.0	97.4	97.6	97.9	98.0	98.0	98.0
Residue, per cent	0.5	0.3	0.7	1.0	1.0	0.9	0.7	0.7	1.0	0.7	0.8	0.7	0.7	0.7	0.8	...	...
Loss, per cent	1.6	1.5	1.3	1.5	1.2	1.1	1.5	2.3	1.3	1.5	2.2	1.9	1.7	1.4	1.2	1.0	1.0
Barometric pressure, mm. of mercury	750	750	756	756	756	756	756	756	756	756	750	756	750	750	750	...	...
Sulphur[c], per cent	0.07	0.03	0.02	0.07	0.05	0.05	0.08	0.04	0.03	0.06	0.05	0.03	0.03	0.03	0.04	0.025	0.019
Reid vapor pressure[d] at 100 deg. fahr., lb. per sq. in.	7	7	5	6	5	6	7	7	7	8	8	5	5	6	5	..	6.5
Corrosion test[e]	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	...	...
Acid heat[f], deg. fahr.	50	61	1	4	56	47	45	34	90	45	131	18	65	70	99	1	2
Gum[g], mg. per 50 ml.	2	2	0	10	0	4	2	2	2	2	2	2	1	1	0	1.4	...

[a] While this table covers the same 15 gasolines indicated in Fig. 6, there is no relationship between the two series of code letters and numbers.
[b] A.S.T.M. method D 86-30. Percentages are those recovered in receiver.
[c] A.S.T.M. method D 90-30 T.
[d] A.S.T.M. method D 323-31 T.
[e] A.S.T.M. method D 130-30.
[f] The increase in temperature when 10 ml. of 95 per cent sulphuric acid were added to 50 g. of gasoline while being well stirred. Distilled water gave a temperature increase of 72 deg. fahr. by this method in the apparatus employed.
[g] See Air-Jet Method for Determining Gum in Gasoline, S.A.E. Transactions, vol. 26, p. 484 (1931).

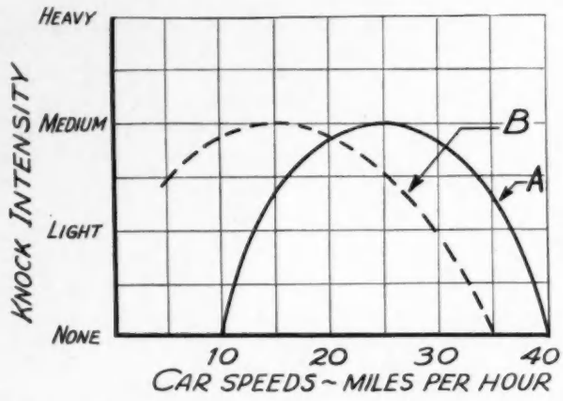


Fig. 3—Comparison of the Maximum Knock Intensity of the Fuel to Be Rated with That of the Reference Fuel, Regardless of the Speed at which the Maximum Knock Occurred, Instead of Comparing the Knock Intensities at the Same Speed

Cars 1 and 3, by matching the knock intensity of the reference fuel with that of the test fuel at the same speed and by comparing the speeds at which knock died out. In Car 1 this fuel knocked from 10 to 34 m.p.h., the knock disappearing at 34 m.p.h. In Car 3, which was of different make and equipped with a vacuum-spark control, the fuel knock was first evidenced at 30 m.p.h. and disappeared at 54 m.p.h.

In Car 1 the rating of *RT*-11 was 60 per cent *C*-6 in *A*-2—apparent octane No. 65—from 10 to 20 m.p.h.; and at the knock-disappearing point, 34 m.p.h., 50 per cent *C*-6 in *A*-2—apparent octane No. 62.5—the total spread being only 10 per cent *C*-6, or about 2.5 octane numbers. In Car 3, on the other hand, the rating of this same fuel was 65 per cent *C*-6 in *A*-2—apparent octane No. 67—at 30 m.p.h.; 35 per cent *C*-6 in *A*-2—apparent octane No. 58—at 40 m.p.h.; and 25 per cent *C*-6 in *A*-2—apparent octane No. 56—at the speed at which knock died out; that is, 54 m.p.h. The rating for this fuel, using just two cars, thus ranged anywhere from 25 to 65 per cent *C*-6 in *A*-2—apparent octane No. 56 to No. 67—depending on the car and the speed at which the rating was made.

Not only do different cars rate the same fuel differently, but different fuels act differently in the same car. Fig. 2 shows also the ratings of fuel *UT*-1 in Car 3. This fuel, *UT*-1, has practically the same rating at all speeds; whereas the rating of fuel *RT*-11 in the same car varies from 65 per cent *C*-6 in *A*-2—apparent octane No. 67—at the lower speeds, to 25 per cent *C*-6 in *A*-2—apparent octane No. 56—at the higher speeds.

The problem, therefore, was to analyze all the data and try to determine what was a significant road rating for each of the 15 fuels; and, if such ratings could be found, to determine whether they were reproducible and easily obtainable.

It was thought that a significant rating might be one based on a comparison of the maximum knock intensity of the fuel to be rated with that of the reference fuel, regardless of the speed at which the maximum knock occurred, instead of comparing the knock intensities at the same speed. For instance, if the knock intensity of a fuel varies with the speed as shown diagrammatically by Curve *A* in Fig. 3, with a maximum knock occurring at 25 m.p.h., then the user might reasonably consider it equal to another fuel which knocked with the same maximum knock intensity, even if this occurred at a different speed, as shown diagrammatically by Curve *B*.

Figs. 4 and 5 show, respectively, for Cars 1 and 3, the knock-intensity data including the knock-disappearing points for the test fuel *RT*-11 and the reference fuels, from which the ratings shown in Fig. 2 were obtained. Figs. 4 and 5 show also how the knocking characteristics of a given fuel may vary from one car to another. Thus, referring to Fig. 4, the maximum intensity of knock for both the test fuel and the reference fuel occurs at 10 to 15 m.p.h., the intensities then decreasing quite rapidly with increasing speeds at very nearly the same rate.

However, in Car 3, using the same fuel, as shown in Fig. 5, the intensity of knock increases with increasing speed, reaching a maximum at the comparatively high speed of 40 m.p.h.; then it decreases until it finally reaches 0 at 54 m.p.h. The reference fuels in this case had a different characteristic, the maximum knock intensity being reached between 30 and 35 m.p.h. and then decreasing with increasing speed, this difference accounting for the wide spread in the ratings of *RT*-11 shown in Fig. 2.

For example, if the speed at which knock disappears were used as a basis for rating, the test fuel would rate equal to a mixture of 25 per cent *C*-6 in *A*-2—apparent octane No. 56—which was the rating shown in Fig. 2 at that speed. Obviously, 25 per cent *C*-6 in *A*-2—apparent octane No. 56—

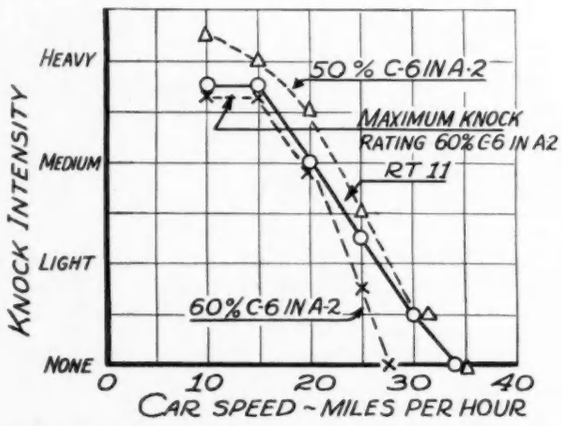


Fig. 4—Knock Intensities Observed in Rating Fuel *RT*-11 in Car 1

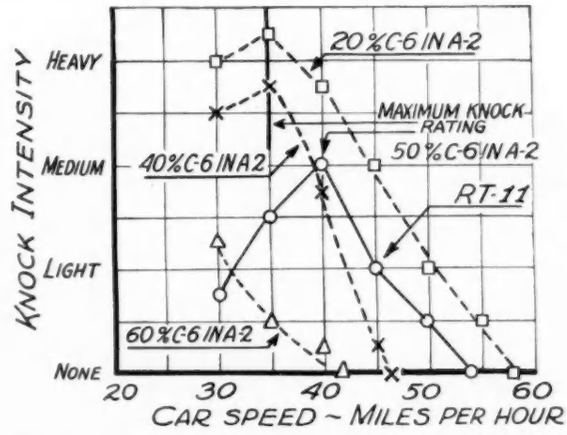


Fig. 5—Knock Intensities Observed in Rating Fuel *RT*-11 in Car 3

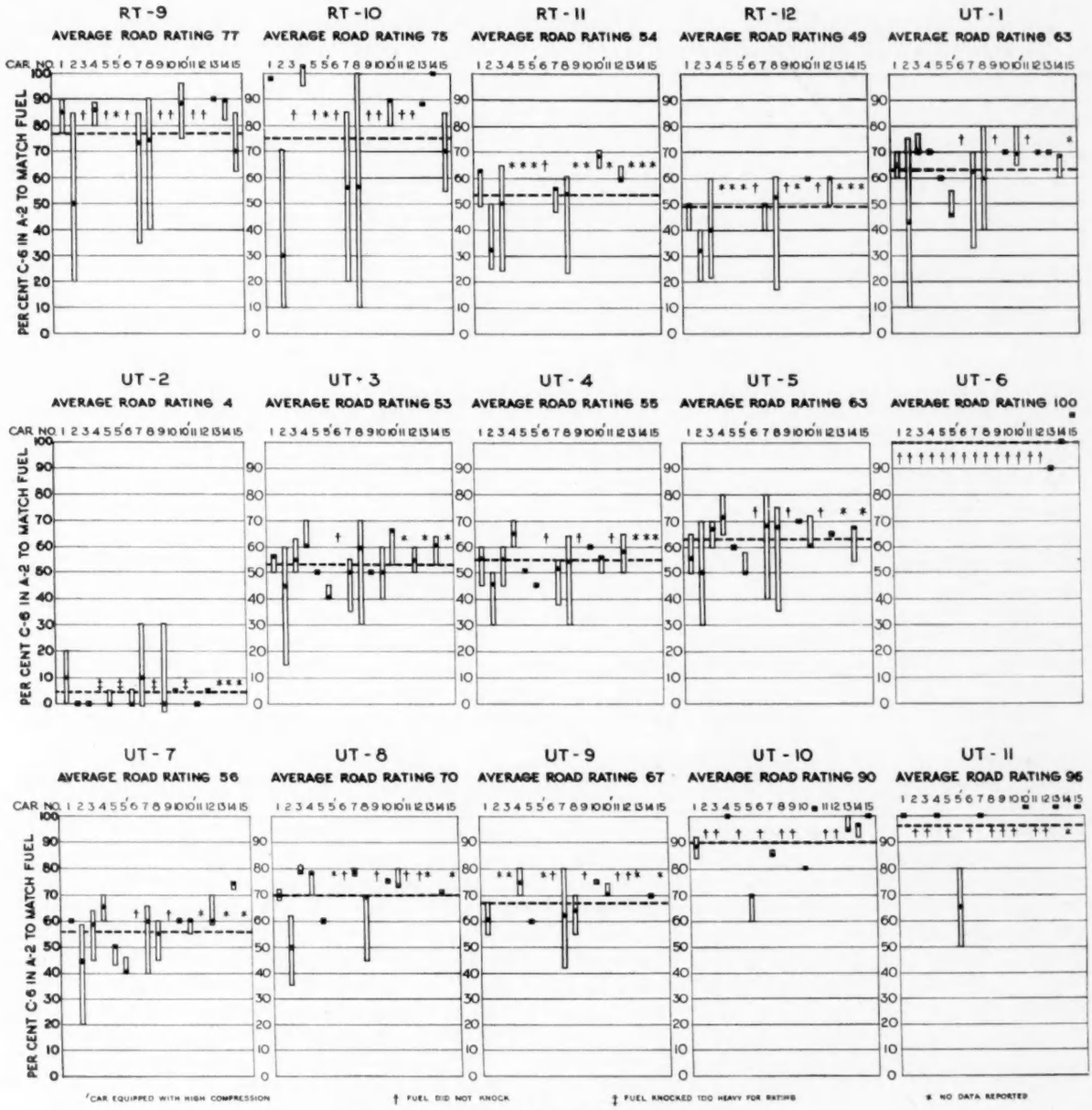

RT - 9
AVERAGE ROAD RATING 77
RT - 10
AVERAGE ROAD RATING 75
RT - 11
AVERAGE ROAD RATING 54
RT - 12
AVERAGE ROAD RATING 49
UT - 1
AVERAGE ROAD RATING 63
UT - 2
AVERAGE ROAD RATING 4
UT - 3
AVERAGE ROAD RATING 53
UT - 4
AVERAGE ROAD RATING 55
UT - 5
AVERAGE ROAD RATING 63
UT - 6
AVERAGE ROAD RATING 100
UT - 7
AVERAGE ROAD RATING 56
UT - 8
AVERAGE ROAD RATING 70
UT - 9
AVERAGE ROAD RATING 67
UT - 10
AVERAGE ROAD RATING 90
UT - 11
AVERAGE ROAD RATING 96
CAR NO. 1 2 3 4 5 5' 6 7 8 9 10 10' 11 12 13 14 15
PER CENT C-6 IN A-2 TO MATCH FUEL
'CAR EQUIPPED WITH HIGH COMPRESSION
† FUEL DID NOT KNOCK
‡ FUEL KNOCKED TOO HEAVY FOR RATING
* NO DATA REPORTED

Fig. 6—Uniontown Road-Test Knock-Ratings

This is a graphic summary plotted from individual charts indicating the knock intensities and the knock ratings of each fuel in each car

does not represent the rating of *RT*-11 in Car 3; because, although this fuel produces a medium knock in this car at 40 m.p.h., the reference-fuel mixture containing 25 per cent *C*-6 in *A*-2 would produce a heavy knock at 35 m.p.h. Likewise, if the knock intensity at a given speed were used, such as 40 m.p.h., which is the speed at which the knock intensity was greatest for the test fuel, a rating equal to about 35 per cent *C*-6 in *A*-2—apparent octane No. 58—would be obtained. But 35 per cent *C*-6 in *A*-2 would produce a heavy knock at 35 m.p.h., which is greater than that produced by the test fuel at any speed; hence a user might be expected to judge the 35 per cent *C*-6 in *A*-2 mixture to be worse than the test fuel.

However, referring again to Fig. 5, if *RT*-11 is compared with the reference-fuel mixtures on the basis of the maximum knock produced by both *RT*-11 and by the reference fuels, it will be seen that *RT*-11 produces a knock equal in its maximum intensity to that of a reference-fuel mixture containing about 50 per cent of *C*-6 in *A*-2—apparent octane No. 62.5. Thus, a rating of 50 per cent of *C*-6 in *A*-2—apparent octane No. 62.5 is obtained. This particular method of obtaining a road rating was developed at Uniontown, and is termed the "Maximum-Knock Method."

The continued application of the analysis to additional cars and fuels brought increasing conviction to those making the tests that the ratings obtained in this way constituted the most logical method to determine a road rating of a fuel in any particular car.

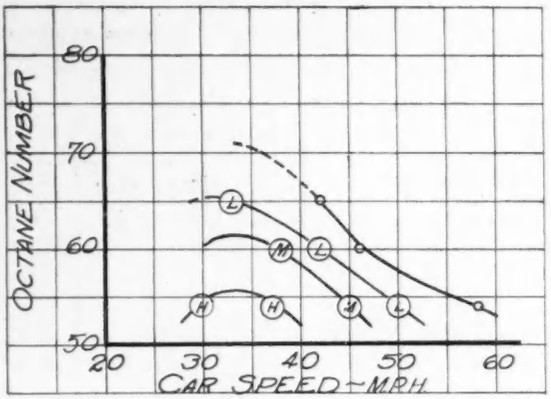


Fig. 7—Chart Representing the Knocking Characteristics of Car 3, Constructed from the Data Shown in Fig. 5

Essential Features of the C.F.R. Road-Test Method for Conducting Antiknock Tests

The road-testing method developed at Uniontown was approved by the Cooperative Fuel Research Committee at its meeting on Sept. 12, 1932, and is to be known as the C.F.R. Road-Test Method for Conducting Antiknock Tests on Motor Gasolines. According to this procedure, road knock-ratings on motor gasolines shall be made by comparing the sample to be rated with a reference fuel; this comparison to be of the maximum knock intensity produced by the sample and that of the reference fuel, without regard as to whether maximum knock occurs at the same or different speeds for the sample and the reference fuel.

More specifically, in rating a fuel in a car by this method it is necessary to determine:

(1) The relative knock intensities produced by the sample at different speeds in high gear during either slow acceleration or slow deceleration with substantially identical vehicle loading.

(2) The relative knock intensities produced by the reference fuels at different speeds under the same test conditions during a similar period of slow acceleration or deceleration. From these data the speed required to produce the maximum knock intensity for each fuel, that is, the sample and the reference fuels, is determined.

(3) Finally, the knock intensity produced by the sample at its speed for maximum knock is to be bracketed between knock intensities produced by two reference fuels at their maximum knock speeds.

The rating is then expressed in terms of a reference fuel which will produce a maximum intensity that matches the maximum knock intensity produced by the sample to be rated. In making ratings by this method, it is to be understood that they are to be made at full throttle and within a speed range of 15 to 50 m.p.h.

Summary of Uniontown Data

A summary of all the data obtained at Uniontown is given graphically in Fig. 6, in which the knock ratings of each fuel, expressed as a percentage of reference fuel *C*-6 in reference fuel *A*-2, are plotted car by car. The maximum spread found between ratings made at different speeds is indicated by the vertical bars, and the average of all maximum knock ratings, that is, ratings obtained by comparing the maximum intensity of knock produced by the test fuel with that produced by the reference fuels, is represented by the heavy horizontal bars.

For example, Fig. 2 shows that one group of observers found the ratings of *RT*-11 in Car 3 to vary from 25 per cent of *C*-6 in *A*-2 to 65 per cent of *C*-6 in *A*-2 with a maximum knock rating, as derived from Fig. 5, of 50 per cent of *C*-6 in *A*-2. This is represented in Fig. 6 by the vertical bar under *RT*-11, Car 3, extending from 25 to 65 per cent of *C*-6 in *A*-2 and the heavy horizontal bar at 50 per cent of *C*-6 in *A*-2.

In this particular illustration, Fig. 2, the same group of observers reported the two extreme ratings, but this did not always happen. In any case, only the extreme ratings are represented by the length of the vertical bars, regardless of whether the extremes were obtained by one group or by different groups. This spread does not indicate a variation between groups; it represents a definite reproducible change in ratings with changes in the car speed at which the ratings were made, regardless of whether the ratings were made during acceleration, deceleration or at constant speed. The variation between groups at any particular speed was seldom more than 10 per cent of *C*-6 in *A*-2, or the equivalent of 2.5 octane numbers, and was usually less than this amount.

Fig. 6 shows also that the maximum knock ratings for a given fuel did not vary over such a wide range from car to car as did the rating obtained by comparing knock intensities of the test fuel with the reference fuels at various speeds. This is especially true for the commercial fuels of the *UT* series, and is a further indication that the maximum knock rating is a significant one. Because of the wide spread in ratings obtained for a given fuel by other methods, and the belief existing among those at work on the problem that the maximum knock rating was a significant one, only the maximum knock ratings were considered in the final analysis to obtain the most representative road rating of each fuel.

Accordingly, all the maximum knock ratings obtained on each fuel, including ratings in all the cars in which that particular fuel was rated, were averaged arithmetically and the average maximum knock rating thus obtained was accepted as the most representative road rating of each fuel. The average road ratings obtained in this way for each fuel are shown as heavy dotted lines in Fig. 6. Ratings higher than 100 per cent *C*-6 in *A*-2 reported in this work were obtained by adding tetraethyl lead to reference fuel *C*-6 and extrapolating the *C*-6 and *A*-2 reference-fuel calibration-curve to the octane number of the leaded mixture.

Laboratory Correlation

In the laboratory correlation work which followed an attempt was made to obtain correlation with these average ratings which represent neither the highest ratings nor the lowest ratings obtainable on a given fuel.

Finally, these road ratings represent the collective findings of 15 technical men working intensively for a period of about three weeks. These men were particularly selected for their expertness in the field of knock testing. During this time more than 2500 test runs were made on the Uniontown Hill, and approximately 10,000 observations of knock intensity, representing over 2000 knock ratings, were recorded. The data were plotted on charts indicating the knock intensities and the knock ratings of each fuel in each car, and from these individual charts the final graphic summary shown in Fig. 6 was prepared.

No individual laboratory has available enough trained experts to approach this quantity of work even over a long period of time. Cooperative effort alone is responsible for the mass of data collected.

Application to Automotive Engine Design

The data which were obtained in the Uniontown tests contain several points of particular interest to the automotive engineer. First, the technique followed suggests immediately a method of recording the knocking characteristics of an engine. A series of standard reference fuels of known octane number was used and the knock intensities during operation on these fuels was observed under some standard conditions of operation.

For example, Fig. 7 is a chart representing the knocking characteristics of Car No. 3 constructed from the data shown in Fig. 5. Using as coordinate axes octane number and car speed, the knock intensities observed for each reference fuel are plotted above the car speed at which that degre of knock was observed. Thus, for 20 per cent *C*-6 in *A*-2—apparent octane number 54—knocking was heavy from 30 to 37 m.p.h. This information is indicated in Fig. 7 by *H* within a circle at 30 and 37 m.p.h. at ordinates corresponding to an octane number of 54. Similarly, on this same fuel, *M* indicates a medium knock at 45 m.p.h. and *L*, a light knock at 50 m.p.h. The small circle at 58 m.p.h. indicates the speed at which knock disappeared.

Applying the foregoing method of plotting to the other reference fuels, 40 per cent *C*-6 in *A*-2—apparent octane No. 60 and 60 per cent *C*-6 in *A*-2—apparent octane No. 65—produces the chart shown in Fig. 7, connecting lines having been drawn to indicate regions of approximately equal knock intensity.

Although these data are not as complete as might be desired, having been obtained incidentally during the rating of *RT*-11, they are sufficient to illustrate what can be done toward expressing in graphic form the knocking characteristics of a particular automobile. Thus the Fig. 7 chart shows that Car No. 3 produced its maximum knock on the reference fuels at a speed of from 30 to 35 m.p.h., and that at wide-open throttle a fuel of octane No. 70 could be expected to be free from knock at any speed. A fuel of octane No. 60 would produce a medium knock from approximately 30 to 40 m.p.h. and the knock would disappear at about 45 m.p.h. A fuel of octane No. 50 would knock throughout the entire speed range. These data, of course, represent an approximation to the extent that different observers may differ somewhat in their judgment of the various degrees of knocks, although the speed at which knocking just disappears is usually definite within 1 or 2 m.p.h. Further factors—which cause these data to represent approximations but for which in practice corrections can be applied—are carbon deposit, elevation and atmospheric conditions.

Acknowledging these limitations, the following tabulation has been made, in so far as possible from the data available, of the approximate antiknock fuel requirements for knock-free operation above 15 m.p.h. of the cars used in the Uniontown tests. Attention is directed to the fact that, although

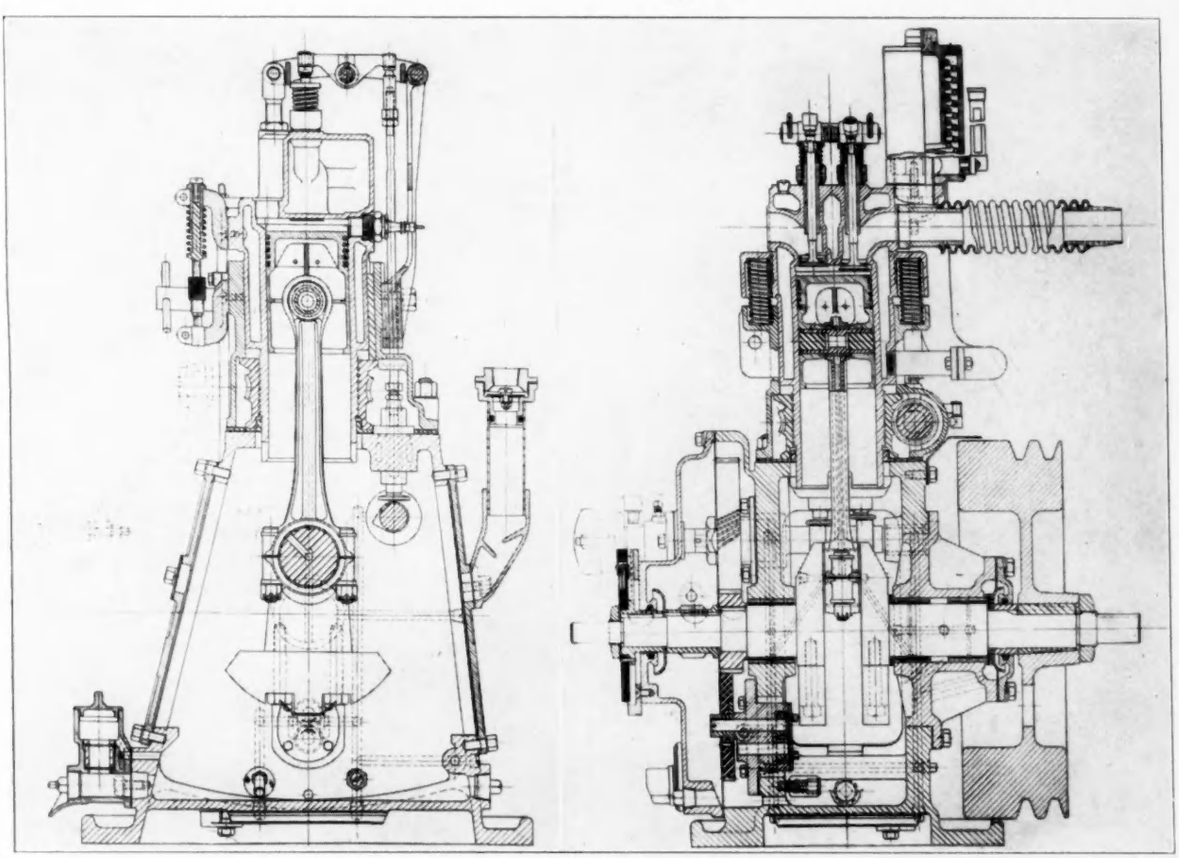


Fig. 8—Cross-Sectional Views of the C.F.R. Engine

this is believed to be a representative group of cars, the amount of carbon deposit in each engine was unknown.

Car. No.	Octane No. of Reference Fuel for Knock-Free Operation
1	76-78
2	66-68
3	71-73
4	76-78
5	65-67
5*HC*	78-80
6	58-62
7	76-78
8	76-78
9	63-65
10	70-72
10*HC*	78-80
12	72-74
13	76-78
14	78-80
15	82-84

The average requirement for knock-free operation in the standard compression cars under the prescribed test conditions appears from these data to be from 70 to 72 octane numbers. This average is significant when considered in connection with the average of 60.8 octane number for non-premium fuels and 75.6 for premium-grade fuels reported in the Bureau of Mines' Twenty-Fourth Semi-Annual Motor-Gasoline Survey of gasolines collected in August, 1931.

Fig. 7 shows that a difference of 10 octane numbers may mean the difference between a medium to heavy knock and no knock at all.

In addition to this information on the rating of the anti-knock requirements of various cars, the Uniontown data disclose one very significant fact which had not been very widely recognized previously. This is that in certain cars different types of fuel vary appreciably in the rate of change of knock intensity with car speed. This behavior has already been noted in the discussion of Figs. 4 and 5 and accounts for variations between fuels in the speed at which maximum knock occurs. It also explains why the knock ratings of certain fuels change with changes in car speed, as shown by the ratings of *RT*-11 in Car 3, referred to in Fig. 5.

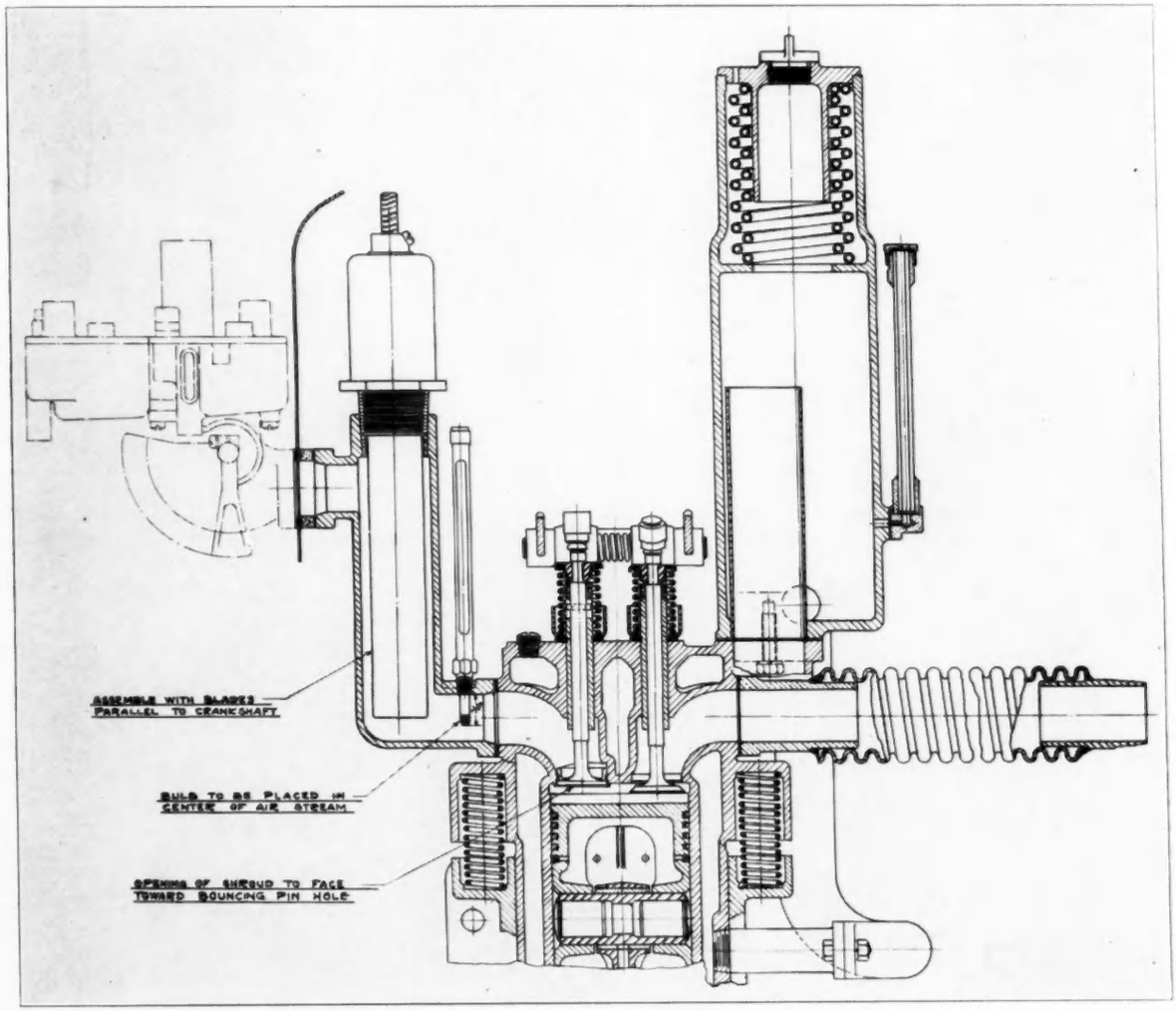

ASSEMBLE WITH BLADES PARALLEL TO CRANKSHAFT
BULB TO BE PLACED IN CENTER OF AIR STREAM
OPENING OF SHROUD TO FACE TOWARD BOUNCING PIN HOLE

Fig. 9—Sectional View of the C.F.R. Engine Cylinder Head Showing Electric Mixture Heater, Shrouded Intake Valve and Improved Type of Vapor Condenser

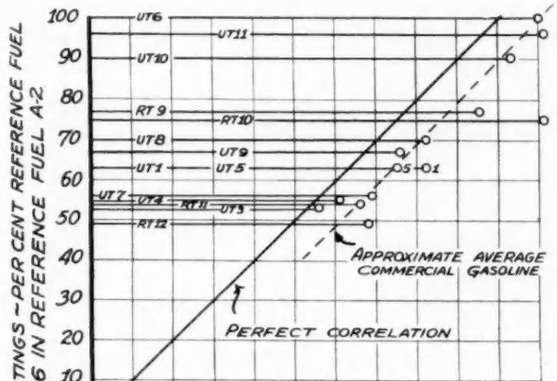


Fig. 10—Road-Test Correlation with the C.F.R. Engine by C.F.R. Research Procedure

The test conditions were: Speed, 600 R.P.M.; jacket temperature, 212 deg. Fahr.; carbureter setting for maximum knock; spark timing, 22.5 deg. at a 5.0:1 compression ratio; and wide-open throttle.

In the majority of the cars the maximum intensity of knock with all fuels occurred at a low speed, 10 to 15 m.p.h. This was true of even those fuels that knocked up to comparatively high speeds. Exceptions to this general rule of low-speed maximum knock-intensity were Cars 2, 5*HC*, 3, 8 and, in in some cases, 7, where the maximum knock-intensity occurred at comparatively high speeds.

The effect of the high-compression heads which were used on Cars 5 and 10 is interesting. In Car 5, with the low-compression head, the maximum knock-intensity occurred at low speeds, 10 to 20 m.p.h. with all the fuels which could be rated; whereas, with the high-compression head, the maximum intensity occurred in most cases at high speeds over 50 m.p.h. Using Car 10 with both the low and high-compression head, the knock intensity decreased with increasing speeds. With Car 5 the high-compression head gave ratings lower in every case, from 6 to 15 per cent *C*-6 in *A*-2, than when using the lower-compression head. With Car 10 the ratings in most cases were more nearly alike; but, with one fuel, *UT*-3, the high-compression head gave a rating higher by 15 per cent *C*-6 in *A*-2 than did the low-compression head.

Obviously, neither the automobile manufacturer nor the petroleum refiner desires that the knock rating of certain types of fuel should depreciate with respect to others with increased engine speed, so the question arises: What are the underlying factors which cause this depreciation of certain types of fuel?

It is fairly certain from the data shown in Fig. 6 that certain factors of engine design contribute to this effect, since Cars 2, 7 and 8 differ so conspicuously from the others by the wide spread in ratings which these cars show at various speeds, particularly for *RT*-9 and *RT*-10. This is a subject which is becoming increasingly important in the design of engines of high antiknock requirements and which calls for further investigation.

The second contributory factor to the requirement for knock-free operation is, of course, the peculiarities of the type of fuel used. Thus the data in Fig. 6 indicate that Cars 1 and 4 require a better fuel than Car 2. This is true for the reference fuels or one such as *UT*-9, which did not knock in Car 2 but produced a knock of medium intensity in Cars 1 and 4. However, some fuels might be considered as satisfactory when used in Cars 1 and 4; but not in Car 2. Thus *RT*-10 produced a heavy knock at 35 m.p.h. in Car 2, whereas this same fuel barely knocked in Cars 1 and 4; also, fuels *UT*-1, *UT*-3, *UT*-5 and *UT*-7 all knocked with equal or greater intensity in Car 2 than in Car 1, the maximum intensity occurring at a speed of 35 m.p.h. in the former and at 10 to 15 m.p.h. in the latter.

Likewise, Cars 7 and 8, though having approximately the same antiknock requirement when determined with the reference fuels as Cars 1 and 4, produced a heavy knock with fuel *RT*-10 at 40 to 50 m.p.h. On the other hand, fuels *UT*-10 and *UT*-11 barely knocked or escaped knock entirely in all four cars.

Laboratory Correlation at Waukesha, Wis.

Having obtained a significant road rating for 15 fuels, 11 of them being representative commercial gasolines, the Road-Test Correlating Subcommittee was ready to begin the second phase of its work, which was to determine what modification of the present C.F.R. engine and procedure would be necessary to obtain knock ratings that would correlate as closely as possible with the road ratings found at Uniontown.

Since the cooperative method had proved to be so successful at Uniontown, it was applied also to this second phase of the problem. H. L. Horning, president of the Waukesha Motor Co., and an active member of the C.F.R. Detonation Subcommittee since its inception, generously offered complete facilities for conducting cooperative tests in the laboratories of the Waukesha Motor Co. This offer was accepted, and the correlating work was conducted at Waukesha with identically the same fuels used in the road tests at Uniontown.

In accordance with the plan outlined by the Road-Test Correlating Subcommittee to allow each participating organization to be represented by one man, the following men and their respective organizations contributed to the work:

W. G. Ainsley, Sinclair Refining Co.
H. W. Best, Yale University
J. M. Campbell, General Motors Corp.
W. M. Holaday, Standard Oil Co. (Ind.)
K. L. Hollister, The Texas Co.
G. A. Hope, Standard Oil Co. (N. Y.)
L. A. Hunt, Ethyl Gasoline Corp.
C. B. Kass, Standard Oil Development Co.
S. P. Marley, Vacuum Oil Co.
T. B. Rendel, Shell Petroleum Corp.
G. C. Rodgers, U. S. Bureau of Standards
J. R. Sabina, The Atlantic Refining Co.
C. B. Veal, Society of Automotive Engineers, Inc.; secretary, Cooperative Fuel Research Committee
H. M. Wiles, Waukesha Motor Co.

H. K. Cummings and N. R. White, of the U. S. Bureau of Standards, and K. T. Winslow and A. W. Pope, of the Waukesha Motor Co., rendered valuable assistance to the above-named operating group.

Seven C.F.R. engines were placed at the disposal of the Committee at the Waukesha laboratory. One of these engines was maintained throughout the tests as a standard C.F.R. engine, without modification, in strict accordance with the requirements of the C.F.R. procedure then current, and was employed for reference and check purposes. The other six engines were used continuously to test the effects of various modifications in the C. F. R. engine and procedure. During

the two and one-half weeks of test work, 68 modifications in procedure and approximately 650 individual knock ratings were made.

At the outset of the work two changes in the C.F.R. engine shown in Figs. 8 and 9 were made in the provision of:

(1) A shrouded intake valve designed to give the charge a swirling motion as it enters the combustion chamber. The purpose of this was to give more uniform knocking and steadier knock-meter readings.
(2) An improved type of vapor condenser and the elimination of the circulating pump.

These two changes proved effective throughout the work.

The first task before the laboratory-operating group was to determine what degree of correlation existed between ratings made by the then current C.F.R. knock-testing procedure, and now known as the "C.F.R. Research Method," and the road ratings obtained at Uniontown. This relationship is shown in Fig. 7 in which the road ratings are plotted on the vertical axis against the C.F.R. ratings by the Research Method on the horizontal axis. Exact correlation between road ratings and the laboratory ratings would be shown by points falling on the 45-deg. line bisecting the angle between the two axes.

The Fig. 10 chart shows a decided lack of correlation, and indicates that the average discrepancy between the C.F.R. engine ratings by the then current procedure and the road ratings for the commercial fuels was in general of the order of magnitude of 10 per cent of reference fuel *C*-6 in *A*-2, or the equivalent of about 2.5 to 3.0 octane numbers with a maximum of 5 octane numbers. For the cracked naphthas the discrepancy was even greater, amounting to as much as 35 per cent of reference fuel *C*-6 in *A*-2, or the equivalent of 9 octane numbers in the case of fuel *RT*-10.

Since these data established the fact that ratings made by the then current C.F.R. knock-testing procedure did not correlate with the road results, the problem resolved itself into one of so modifying that C.F.R. procedure as to obtain better correlation between the results of the laboratory test and the road test. In making the necessary modifications, the committee aimed to obtain the best correlation possible by means which would involve the minimum amount of change in the existing equipment. An effort was made to reproduce normal automobile-engine operating-conditions insofar as possible and to develop a method that would lend itself most readily to routine practice and by which knock ratings could be made on fuels varying in antiknock quality over a wide range.

With these principles in mind, the engine-operating variables which various cooperating laboratories had already found to be effective in modifying knock ratings were tried. These variables were: (*a*) engine speed; (*b*) mixture temperature; (*c*) jacket temperature; (*d*) throttle opening; (*e*) valve timing; and (*f*) piston temperature. A study was made of the effect upon road-test correlation of changes in each of these variables, both singly and in various combinations.

Experiments with several modified pistons designed to operate at higher temperatures were unsuccessful in bringing about better correlation, and auto-ignition occurred with some of these pistons.

Considerable experiment revealed that reasonably good correlation with the road ratings could be obtained by any one of four general methods, all of which involved an increase in speed above 600 r.p.m. and little if any effect being caused by variations in operating conditions so long as the speed was maintained at 600 r.p.m. These methods were:

(1) Heating the intake mixture, keeping the jacket temperature at 212 deg. fahr.
(2) Increasing the jacket temperature above 212 deg. fahr. by using ethylene glycol as the cooling medium.
(3) Throttling the intake by means of the carbureter throttle.
(4) Throttling the exhaust by changing the timing of the exhaust valve so that it closed earlier—up to 37 deg. before top dead center—by means of a special camshaft.

The degree of change required in each of these four methods depended on the speed. Speeds of 600, 900, 1000, 1100 and 1200 r.p.m. were tried. Finally, 900 r.p.m. was chosen as the most satisfactory speed since it is high enough to be within the range of the automotive engine speeds of which knock commonly occurs and yet low enough to expedite laboratory testing with the present engine and customary quantities of fuel samples.

Although correlation was obtained with all four of the foregoing methods, the first two were definitely more satisfactory than the third and the fourth, and the latter two were, therefore, discarded. The method involving throttling was unsatisfactory; because, to accomplish the desired correlation, it was necessary to throttle to such an extent that only the very upper range in compression ratios, that is, ratios from 8:1 to 10:1, could be utilized. Thus, with the fixed amount of throttling required for ordinary commercial fuels, the fuels of higher antiknock quality could not be rated due to the limitation in compression ratios available. This procedure also involved a very wide departure from actual automobile-engine operating conditions. Further, the operating group at Waukesha felt that, because of the delicacy of adjustment which, according to their experience, was required to obtain correlation, this method would be unsuitable for commercial testing. The fourth method, involving changes in exhaust-

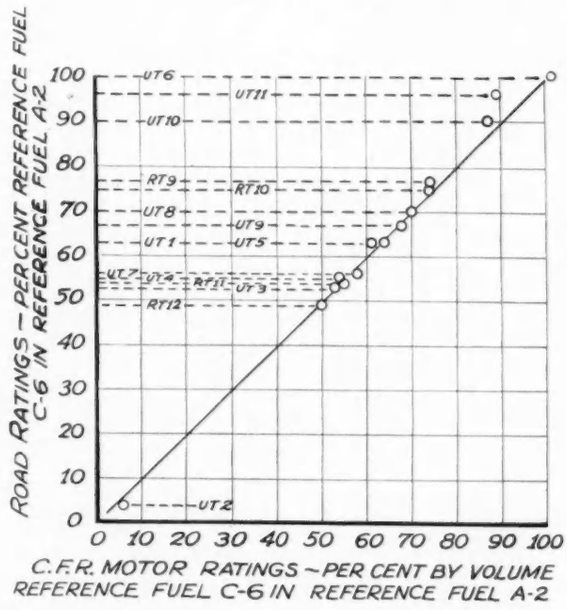


Fig. 11—Road-Test Correlation with C.F.R. Engine by C.F.R Motor-Method Procedure

The test conditions were: Speed, 900 R.P.M.; jacket temperature, 212 deg. Fahr.; mixture temperature, 300 deg. Fahr.; carbureter setting for maximum knock; spark timing, 25 deg. at a 5.0:1 compression ratio; and wide-open throttle

Table 3—Summary of Ratings on Fuels Tested at Uniontown

Fuel	C.F.R. Research Method		Road Ratings		C.F.R. Motor Method	
	Reference Fuel *C* in Reference Fuel *A*, Per Cent	Equivalent Octane Number	Reference Fuel *C* in Reference Fuel *A*, Per Cent	Equivalent Octane Number	Reference Fuel *C* in Reference Fuel *A*, Per Cent	Equivalent Octane Number
RT-9	95	76	77	70	74	70
RT-10	111	80	75	70	74	70
RT-11	66	67	54	64	55	64
RT-12	68	68	49	62	50	62
UT-1	82	72	63	66	64	67
UT-2	1	50	4	50	6	50
UT-3	56	64	53	63	53	63
UT-4	61	66	55	64	54	64
UT-5	75	70	63	66	61	66
UT-6	110	80	100	77	101	77
UT-7	69	68	56	64	58	65
UT-8	82	72	70	68	70	68
UT-9	76	70	67	68	68	68
UT-10	103	77	90	74	87	73
UT-11	111	80	96	75	89	74

valve timing, was likewise discarded because it resulted in similar difficulties, and the accuracy of timing required was not believed to be within manufacturing limits.

Thus, with modified pistons and also with throttling and special camshafts eliminated, the following three variables remained with which to bring about the desired correlation: (*a*) speed; (*b*) mixture temperature; and (*c*) jacket temperature. By combining an increase in speed from 600 r.p.m. to 900 r.p.m. with each of the other two variables, two satisfactory methods were developed for obtaining correlation with the Uniontown road ratings. The first involved the following modifications in the current C.F.R. procedure:

(1) Speed, 900 r.p.m.
(2) Jacket temperature, 330 deg. fahr.
(3) Mixture temperature, 225 deg. fahr.
(4) Spark timing, 26 deg. before top dead-center at 5.0:1 compression ratio, the timing mechanism remaining unchanged
(5) A shrouded intake valve
(6) Elimination of the circulating pump

This method was the second choice of the operating group and, since it involved the use of ethylene glycol as a cooling medium, the following method was recommended as more suitable. It will be referred to hereafter as the "C.F.R. Motor Method," as distinguished from the original or C.F.R. Research Method. This new equipment is to be used for both Research and Motor Methods and differs from the then current C.F.R. engine in two respects:

(1) The substitution of:
  (*a*) A shrouded intake valve
  (*b*) An improved type of vapor condenser, as shown in Fig. 9, and
(2) The elimination of the jacket-cooling water-circulating pump

The new C.F.R. Motor Method differs from the C.F.R. Research Method only in three respects involving further definite changes in equipment and procedure, listed as follows:

(1) Under Section 5, Standard Adjustments, item (*a*), engine speed has been changed from 600 r.p.m. for the Research Method to 900 r.p.m. for the Motor Method.

(2) Under Section 5, Standard Adjustments, item (*f*), spark advance, maximum power—automatically adjusted—for the Research Method has been changed to a spark timing of 26 deg. before top dead-center at a compression ratio of 5:1, and the spark advance at other compression ratios follows characteristics imposed by the timing mechanism used with the Research Method.

(3) For the Research Method, mixture temperature is not specified; but a definite mixture temperature of 300 deg. fahr. $\pm$ 2 deg. fahr. is required for the Motor Method. The heat for maintaining this temperature is applied by a special electric heating-unit introduced between the carbureter and the intake port. It is further required that the mixture temperature be measured by a special mercury thermometer, so located in the intake manifold as to measure this temperature at the entrance to the cylinder head.

Proper condition and operation of the test engine should be checked at frequent intervals by using the Motor Method to obtain knock ratings on the special standard reference fuels calibrated for that purpose. The primary reference standard for this purpose consists of a blend of 1-deg. benzene with normal heptane.

Test conditions shall not be regarded as standard for ratings by the C.F.R. Motor Method unless a blend by volume of 65 per cent iso-octane and 35 per cent normal heptane is matched under the specified procedure by a blend by volume of 68 $\pm$ 1 per cent, 1-deg. benzene with 32 $\mp$ 1 per cent normal heptane. At an atmospheric pressure of 760 mm., a compression ratio of approximately 5.3:1 is correct for this determination. Substantial variations in atmopsheric pressure will change the compression ratio required. For routine checking purposes, 1-deg. benzene and the secondary reference fuels *A*-2 and *C*-6, supplied by the Standard Oil Development Co., may be used.

Table 4—Heptane-Octane Calibration Data for Blends of Reference Fuels *C*-6 and *A*-2

Octane in Heptane, Per Cent	Reference Fuel *C*-6 in Reference Fuel *A*-2, Per Cent Equivalent	
	C.F.R. Research Method	C.F.R. Motor Method
74	90	91
70	75	76
60	35	41
50	1.5	5

A blend by volume of 50 per cent 1-deg benzene with 50 per cent *A*-2 is matched under the specified procedure by a blend by volume of 78 $\pm$ 3 per cent *C*-6 with 22 $\mp$ 3 per cent *A*-2. At an atmospheric pressure of 760 mm., a compression ratio of approximately 5.6:1 is correct for this determination. Substantial variations in atmospheric pressure will change the compression ratio required.

Research now under way is expected to lead eventually to a more complete understanding of the controlling factors of test conditions. This will warrant establishing additional control check points to cover adequately the entire range of motor-gasoline knock-ratings.

Correlation with Road Ratings

Fig. 11, showing the correlation between road ratings and ratings on the C.F.R. engine determined by this modified procedure, and Table 3, giving the summary of ratings on the fuels tested at Uniontown, indicate clearly the almost perfect correlation between road ratings of the fuels and the laboratory ratings according to the modified procedure, as well as the degree of improvement in this correlation over that obtainable by the previous method.

Nearly all the ratings obtained by the modified method, as shown in Fig. 11, fall along the 45-deg. line, representing perfect correlation, and do not deviate from this line as the ratings by the then current method deviate from their average line, as indicated in Fig. 10. This fact is an indication that the ratings obtained by the modified method were made under engine conditions that would produce results similar to those obtained by the road ratings.

Octane-number calibration curves obtained by the operating group at Waukesha for mixtures of reference fuel *C*-6 in reference fuel *A*-2, by both the then current C.F.R. procedure and by the modified procedure, are shown in Table 4 and Fig. 12. From these data there appears to be almost no change in the octane-number calibration of the reference-fuel mixtures with the modified procedure. Further work is in progress to establish with greater certainty the calibration of the reference fuels.

For the purpose of getting a check on the reproducibility of the Motor Method, the Committee arranged to have sent to the cooperating members samples of fuels actually being marketed of such characteristics as to cover a wide range of antiknock performance in service, including especially cracked products.

The results so far reported on five fuel samples show an acceptable degree of reproducibility but indicate that a more careful control of knock intensity and other engine-testing conditions may be expected to eliminate such difficulties as have been experienced in the practical application of the method.

Heating of either the intake mixture or increasing the jacket temperature above 212 deg. fahr. was effective in obtaining correlation between road and laboratory ratings. In choosing between heating the intake mixture or increasing the jacket temperature above 212 deg. fahr. as an aid in obtaining correlation between road and laboratory ratings, the latter was not used because the maximum cooling temperature in our present automotive equipment is 212 deg. fahr., which makes it inadvisable to increase the jacket temperature above this figure. On the other hand, the mixture temperature is raised in our automotive engines by both hot-spot—the heat in most cases being furnished by the exhaust gases—and the use of heated intake air taken under the hood. Heating the intake air of the laboratory test engine is undesirable, as it would cause general heating of the car carbureter and hence vapor locking. Therefore heating the intake mixture to 300 deg. fahr. was finally adopted.

These points are brought out not only as the reasons for using these variables in the test procedure but also to show the main factors causing the largest amount of depreciation in the knock ratings from those obtainable by the C.F.R. Research Method to those obtainable by the C.F.R. Motor Method. If these factors are of such vital importance in bringing about correlation with road results, they deserve particular attention from the designing engineer as items to be considered in any effort to develop engines capable of knock-free operation.

Thus, the tests at Uniontown and Waukesha, besides ac-

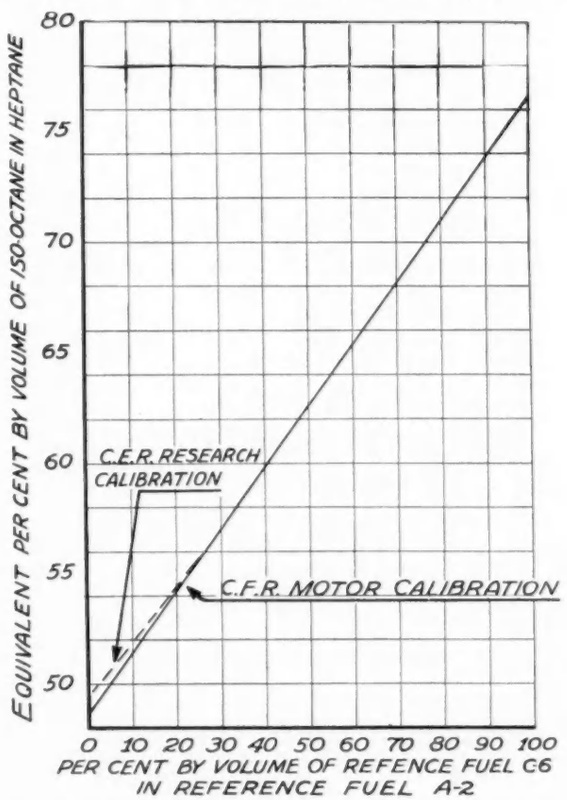


Fig. 12—Calibration of Reference Fuel Mixtures of *C*-6 and *A*-2 against Heptane and Iso-Octane. The data were obtained by the Road-Test Correlation Group at Waukesha, Wis.

complishing their primary purpose, brought out some significant points of interest to the engine designer. They showed that:

(1) Certain fuels are definitely sensitive to some engine-design features which affect their relative antiknock quality.
(2) Several typical commercial fuels have this sensitivity to a greater or less extent.
(3) These features of internal-combustion-engine design can be handled so as to minimize this fuel sensitivity, as was done in the original C.F.R. engine.
(4) Present-day engines vary widely among themselves in the extent to which they make manifest this fuel sensitivity, which indicates that, particularly in some cases, this effect could be diminished without affecting other performance characteristics appreciably and thus permit the use of higher compression ratios with present-day fuels.

New Laboratory Method Approved

The operating group, in rendering its report to the C.F.R. Detonation Subcommittee, expressed the belief that the C.F.R. apparatus and procedure, as modified, not only gives better correlation with the actual performance tests than does the former C.F.R. procedure but also enables knock ratings to be made with greater speed and accuracy than heretofore.

Acting upon the recommendation of the Detonation Subcommittee, approving the report of the operating group, the Cooperative Fuel Research Committee, at its meeting on Sept. 12, 1932, officially approved the modification of the knock-testing procedure, to be known thenceforth as the C.F.R. Motor Method. A Special Subcommittee was delegated to revise the C.F.R. Recommended Practice for Conducting Antiknock Tests in accordance with the adopted changes.

The Cooperative Fuel Research Committee also approved the suggestion of the Detonation Subcommittee that the former C.F.R. method should not be discarded, since it is one on which considerable experience and data have been obtained and is, unquestionably, indispensable from the experimental standpoint as an aid to the refiner in developing suitable gasolines and to the automotive-engine designer in improving the combustion characteristics of his engine. It was, therefore, retained under the name "C.F.R. Research Method."

To summarize, the work of the Detonation Subcommittee, since its last report, had for a guide the thought that the final measure of usefulness of any test method is the extent of its effectiveness in indicating how the material tested will perform in service.

The C.F.R. Engine-Test Method of Knock Evaluation, now designated as the Research Method, is accurate and reproducible to a remarkable degree. Investigation developed, however, that it was not adequately simulating service conditions as judged by the most critical technician or the less critical lay user.

To bring the laboratory method in line with road evaluation of a fuel, a definite technique of road test was evolved that, while not to be considered in commercially determining octane numbers, was regarded by the Committee as sufficiently accurate and reproducible to serve as the first step in the development of a satisfactory laboratory method.

With a satisfactory road-test method available, the next step was to test a representative group of fuels and then to develop a laboratory method which closely approximates the road results. The method finally adopted—a logical outgrowth of the original procedure—evolved by modifications consistent with the development as originally contemplated, meets this requirement with an extremely close approximation of the road observations.

This effective accomplishment is a tribute to the cooperative spirit between the oil and automotive industries as evidenced in the work of the Cooperative Fuel Research Committee. Only the mutual confidence and understanding of each other's problems and the prestige developed for the Cooperative Fuel Research Committee through its years of outstanding accomplishment made this work possible.

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(Appendix)

Authority.—At its meeting at Uniontown, Pa., Aug. 17, 1932, the Detonation Subcommittee of the Cooperative Fuel Research Committee adopted the hereinafter described method of conducting antiknock tests in automotive vehicles on the road. The method was approved by the Cooperative Fuel Research Committee at its meeting on Sept. 12, 1932. Its essential features were published in the paper Correlation of C.F.R. Laboratory Knock Ratings with Behavior of Motor Fuels in Service[9], by C. B. Veal, H. W. Best, J. M. Campbell and H. M. Holaday.

Scope.—The method is not designed to determine octane numbers, but for the purpose of determining the relative antiknock value of fuels in motor vehicles on the road. The method involves a comparison between the fuel to be rated and reference fuels of known antiknock value.

Location for Tests.—An essential for securing useful data in such a test is a long enough stretch of highway either of sufficiently uniform grade or sufficiently level to insure that equilibrium engine conditions can be achieved before data are taken and during the test for a length of time adequate to secure reasonable reproducibility of data.

Equipment.—A second essential is that the vehicle be maintained in good mechanical order so that changes in mechanical condition during test operations may not materially affect the value of the test data for any fuel. Manufacturer's standard adjustments of the various mechanisms of the vehicle are to be preferred. In view of the importance of comparative speed, speedometers or other speed-measuring instruments used should be frequently calibrated. Any deviations from manufacturer's standard adjustments should be reported[10].

Supplies.—Two reference fuels are essential, one of high octane number and one of low octane number. They should be of a type which does not change in performance characteristics within a reasonable time in storage or in use and of a volatility requiring no change in the induction system from the adjustments conventional for ordinary motor fuels[11].

Test Conditions.—Slow acceleration or slow deceleration, in high gear with wide-open throttle shall be employed. The rate of acceleration or deceleration may be maintained "slow" by highway grade, by brakes, or by towing another vehicle on a level road. When comparing two fuels, the load moved and the rate of acceleration or deceleration of the test vehicle shall be maintained as nearly constant as conditions permit.

Substantially, equilibrium conditions for the engine should be secured before each run upon which data are to be taken and maintained until the throttle is opened wide for the test run. With the vehicle in high gear, the throttle shall be opened fully in one motion without lag, and data may be taken as promptly as the accelerator fuel reserve, if any, is consumed. Operation for 100 yd. should be employed to accomplish this if it is not convenient to verify the minimum distance required[12].

Taking of Data.—Engine knock audible to the observers is essential for making comparisons between reference and test fuels. The knock intensity produced by various mixtures of the reference fuels at speeds in the range from 15 to 50 m.p.h. should be determined and compared with the knock intensity, produced by the fuel under test, at the same intervals of road speed.

Alternate runs of the test fuel and different mixtures of the reference fuels shall be made, noting the knock intensity for each fuel at intervals of 5 m.p.h., until a mixture of the reference fuels is found which develops a maximum knock intensity identical with the maximum knock intensity developed by the test fuel, irrespective of the speed at which such knock intensities are developed. Tests must be repeated until all observers are agreed as to the speed at which each fuel develops maximum knock intensity, and as to the selection of the particular mixture of reference fuels developing a knock intensity equal to that produced by the test fuel[13].

Expression of Results.—The road knock-rating of the test fuel is the same as that of the reference fuel mixture which it matches in maximum knock intensity.

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[9]See *Proceedings of the American Petroleum Institute,* Section III, p. 139.

[10]Air-fuel ratio adjustment of the carbureter and spark-advance setting are examples of adjustments referred to and are of particular importance in securing dependable results.

A useful fuel-supply installation comprises a flexible metal tubing leading from the interior of the car to an electrically operated fuel pump mounted conveniently. Connections between this fuel pump and the carbureter and between the metal line within the body of the car and the fuel supply may be made with rubber hose or metal tubing as is most convenient. Portable containers for suitable mixtures of reference fuels are recommended so that the fuel supply can be selected readily from any container and changes made with a minimum of delay in clearing a fuel line. Usual precautions against fire and loss of volatile vapors should naturally be employed.

[11]To permit the . . . . . interchange and comparison of the test data, it is generally desirable to employ secondary reference fuels which are in common use. Two such reference fuels, *A* and *C*, are commercially available through the Standard Oil Co. (N. J.). These fuels have octane numbers of approximately 48 and 76, respectively, and calibration curves are furnished with them as determined in accordance with the C. F. R. Motor Method, giving octane numbers of these fuels blended with each other and with benzene and tetraethyl lead. They may be ordered through the Standard Oil Development Co., 26 Broadway, New York City.

To conform to the requirements for stability in performance, lead tetraethyl is recommended as a knock suppresser when the fuel under test is of higher antiknock value than that of the high antiknock reference fuel.

[12]In conducting tests on a single vehicle, it should be borne in mind that not only do different vehicles rate the same fuel differently but different fuels act differently in the same vehicle. (See Figs. 1, 3, and 4.) A number of vehicles is desirable if broad conclusions are to be drawn from the test results.

[13]A convenient method of making the necessary comparisons employs a graph where the coordinates are the intensity of knock and speed in miles per hour, respectively. The ordinate may consist of the terms light, medium, heavy, 1, 2, 3, a, b, c, and the like, as desired. The abscissa should be laid off from the intercept in increments of 5 m.p.h. over the speed range of the test. (See Fig. 2.) The points may be plotted as promptly as each run is completed on a fuel, or a number of alternate runs on test fuel and various mixtures of reference fuels may be plotted to determine if a bracket has been secured. With mixtures of reference fuel of respectively slightly higher and lower antiknock value than that of the test sample, the sample will be bracketed on the graph at its maximum knock intensity.

To actually match the test sample it is necessary that its maximum knock-intensity peak on the graph be on a level equal with that of the mixture of reference fuels it matches. Blends of reference fuels should be made up in steps equivalent to about 5 octane numbers for convenience in securing the bracket. Actual matching blends can also be made for confirmation of the precise road knock-rating of the test sample.

Aluminum Cylinder Heads Urged as Way to Better Design

By F. F. Kishline

MEASURED gains in performance obtained by using aluminum instead of iron for cylinder head material come from the increased compression ratios possible, Mr. Kishline says, and recommends higher ratios "as a logical means for the engineer to use in creating better transportation."

He gives actual figures taken from observed dynamometer performance showing comparable results on similar engines with aluminum and iron cylinder heads. Desirable features of aluminum heads are presented, after which are discussed design improvements necessary if such heads are to be used successfully.

Differences in combustion phenomena resulting from use of iron and aluminum heads also are outlined.

THE compression ratio of an engine is, of course, also its expansion ratio, and other factors being equal, thermal efficiency improves with any increase in expansion ratio. This is one of the principal contributing factors in obtaining the relatively high efficiency in Diesel engines. Aluminum as a cylinder head material has been found valuable in making possible a considerable increase in this compression and expansion ratio. For years past these ratios have been steadily increasing in automotive engines and this step is merely a further extension of a development which has been progressing in the same direction since the time of Dr. Otto's experiments.

The measured gains in performance obtained by using aluminum as compared with iron for cylinder head material in L-head engines is derived mainly from the increased compression ratio possible with a fuel of a given octane rating. No gain in performance is to be expected if the ratio is not increased. On the contrary a loss will be shown where aluminum is substituted for iron and the ratio left unchanged, particularly at low speeds and low temperatures, unless with the iron head the engine knocks badly when developing its maximum power. In this latter case aluminum will usually prevent the knocking and thereby effect more favorable combustion which in some instances results in a slight overall improvement.

However, the comparisons to follow are with iron heads having 5.5 to 1 ratios and giving very satisfactory service with 62 to 65 octane gasoline. These figures indicating performance are taken from observed dynamometer performance of the same engines under identical conditions of air, water and mixture temperatures and with the same manifold sizes, carbureter sizes, valve sizes and timing, with nothing changed except the cylinder heads. All the figures for iron are the 5.5 to 1 ratio and all the figures for aluminum are the 6.5 to 1 ratio, this being the increase in ratio used in production when aluminum was adopted and was arrived at on the basis of being comparable with the former ratio in iron for freedom from pinging under all conditions.

	Iron	Aluminum
Horsepower, per cu. in.	.34 to .345	.38 to .39
Foot pounds, per cu. in.	.67 to .68	.715 to .72
Fuel consumption, lb. per b.hp-hr. (taken at maximum hp.)	.729	.656
Percentage of Increase: Horsepower	10½ per cent	
Torque	7 per cent	
Fuel Consumption (Decrease)	10½ per cent	
Power plant weight reduction, approximately	5 per cent	
Car weight reduction, approximately	1 per cent	

These are actual test results taken from average performance of each, and are entirely aside from any theories involved.

Some desirable features more difficult of evaluation but none the less definitely present in some degree with the higher ratios are:

1. Better idling, due to 23 per cent less residual burned gas for dilution of the incoming charge.

2. Better starting due to slightly greater vacuum at a given cranking speed, because the engine, having less clearance volume, is more efficient as a pump, and a noticeably faster acceleration or take off after first fire.

3. Lower exhaust gas temperatures because of higher thermal efficiency resulting in lower under hood temperatures and some better exhaust valve life.

[Mr. Kishline is assistant chief engineer, Graham-Paige Motors Corp. This paper was read at the 1933 Annual Meeting of the Society.]